

Guidebook of Part Cleaning Alternatives

“Making Cleaning Greener in Massachusetts”

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INTRODUCTION

Cleaning dirty parts is an important component of many industrial operations and involves removing of contamination (e.g., dirt, oil, fingerprints, flux) from a surface. This function is either necessary for successful part performance in subsequent operations (e.g., plating, welding, assembly) or is desirable aesthetically. This cleaning has traditionally been accomplished using chlorinated solvents in vapor degreasers or immersion systems. The chlorinated solvents most commonly used for metal cleaning include: trichloroethane, trichloroethylene, perchloroethylene, methylene chloride and chlorofluorocarbons (CFCs). Chlorinated solvents are effective cleaners and, in the past, were considered "safe" to workers because they are nonflammable.

However, due to concern over the ozone layer, photochemical smog and adverse health effects, increasingly strict environmental regulations have been promulgated resulting in higher costs associated with the purchase and disposal of chlorinated solvents. Traditional chlorinated solvent cleaning is becoming a process of the past. For many companies, however, changing from a proven process to a new technology is a difficult task. Many alternatives presented as "perfect" solutions are not effective cleaners in all applications, are too expensive for certain purposes, or present safety hazards. This Guidebook is intended to assist in the identification and evaluation of options and in the final selection of the most cost effective and technically feasible cleaning system that will not compromise worker health and safety or environmental protection.

Synonyms and Common Names for Chlorinated Solvents
(names in bold will be used throughout report)
1,1,1-trichloroethane: 1,1,1-TCA, TCA, methyl chloroform
1,1,2-trichloroethylene: TCE, TRIC
perchloroethylene: PCE, PERC, 1,1,2,2-tetrachloroethylene
methylene chloride: dichloromethane, METH, DCM, MeCl
CFC-113: trichlorotrifluoroethane, Freon, Freon TF

CLEANING SURVEYS

Because cleaning issues are common to many industries and because companies need to comply with the Montreal Protocol¹, the Office of Technical Assistance for Toxics Use Reduction (OTA) and the Toxics Use Reduction Institute (TURI) have focused a fair amount of their technical assistance and research efforts on cleaning issues. In 1996, OTA and TURI completed a survey of Massachusetts manufacturers primarily in SIC codes 3400, 3500 and 3600. Information was collected to answer the following questions:

- What cleaning processes, chemicals and substrates are used and what contaminants are

¹Coordinated by the United Nations Environment Programme, the Montreal Protocol on Substances that Deplete the Ozone Layer dictated an end to industrialized countries' production of chlorofluorocarbons, carbon tetrachloride and methyl chloroform by January 1, 1996.

cleaned?

- What information do firms need regarding cleaning issues?
- What are the preferred methods for meeting those information needs?
- What problems have been encountered when switching cleaning systems?

From the survey responses, it was learned that most often oil, grease and dirt were being cleaned off of metal using either chlorinated solvents or aqueous cleaning systems. In addition, for companies that were using chlorinated solvents, SIC 3400 (fabricated metal products) was the one most often represented. The following information needs were identified: names of vendors and the products they supply, current regulatory requirements and case studies of successful conversions. The methods preferred for meeting those needs were written materials (specifically a comprehensive Guidebook), workshops, on-site technical assistance and off-site equipment demonstrations. Fifty-one survey responses mentioned at least one problem or barrier to implementation of an alternative cleaning system. These were combined into four major groups: ineffective cleaning, time requirements, cost and residue remaining on parts. (See Section 1.9 for direct suggestions for addressing these four problems.) The complete survey and results are included in Appendix A. The results of the survey were used to help allocate OTA and TURI resources and this Guidebook was prepared at the suggestion of the survey respondents.

OTA also conducted a separate, more in-depth survey of companies who had switched away from solvents (most were chlorinated) in order to learn about the implementation of the new processes.

Generally, it was learned that regulations were driving the process changes. Worker training was identified as an important component of the implementation process and worker resistance was identified as an unexpected problem. Additional information gained from the survey responses has been included throughout the Guidebook, as appropriate. This complete survey and the results are included in Appendix B.

Aqueous cleaning is the main focus of this Guidebook as it is probably the most popular choice for companies switching away from chlorinated solvents. Because aqueous cleaning is not always an option, information is also offered on semi-aqueous, alternative solvents, abrasives and new or highly specialized technologies.

The Guidebook is organized into the following sections. In section one, it is recommended that steps 1-6 be performed in order and steps 7, 8 and 9 may be performed at any time.

SECTION 1 NINE STEPS TO A NEW CLEANING SYSTEM

This section will assist individuals in thinking about alternatives, helping to evaluate and planning for implementation.

- Step 1: Why Change?** Describes the potential environmental, worker health & safety issues associated with solvent systems.
- Step 2: Launch A Campaign.** Discusses how to form a team to accomplish the cleaning conversion.
- Step 3: Assess Current Operations.** Suggests how to assess current operations in order to determine the exact requirements of a cleaning system.
- Step 4: Identify and Research Alternatives.** Provides references for learning about cleaning alternatives - conferences, trade associations, Internet sites.
- Step 5: Initial Screening of Alternatives.** Suggests how to narrow the number of options for further consideration.
- Step 6: Testing and Implementing Alternatives.** Discusses the lab-scale and pilot-scale testing options for evaluating the effectiveness of the alternatives being investigated.
- Step 7: Financial Analysis.** Provides information on assessing the total cost of the current process and the alternatives.
- Step 8: Regulatory Analysis.** Provides information related to potentially applicable regulations.
- Step 9: Anticipating Problems.** Offers the lessons learned from companies that have already switched.

SECTION 2 ALTERNATIVE CLEANING TECHNOLOGIES

This section defines the alternatives and provides advantages and challenges for each.

SECTION 3 POST-CLEANING: RINSING, DRYING, QUALITY EXAMINATION

This section describes the post-cleaning processes and provides tips for avoiding problems.

SECTION 4 USEFUL TOOLS FOR FINANCIAL ANALYSES

This section provides details of the net present value calculation using a cleaning process example.

SECTION 5 USEFUL TOOLS FOR REGULATORY ANALYSES

This section evaluates the regulatory implications for the alternative cleaning technologies in Section 2.

SECTION 1 NINE STEPS TO A NEW CLEANING SYSTEM

1.1 STEP 1 - WHY CHANGE?

Prior to the 1970s, trichloroethylene dominated the cleaning solvent market. In the mid-1960s it was discovered that trichloroethylene was photochemically reactive and that its emissions contributed to smog formation. This led to limitations on its use. In some cases, these restrictions resulted in the replacement of trichloroethylene by less photochemically reactive solvents. In 1975, trichloroethylene was identified as a carcinogen to mice, and concern was expressed regarding worker exposure to its vapors. Trichloroethylene was often replaced by CFC-113, trichloroethane and methylene chloride as more environmentally acceptable and less toxic replacements in vapor degreasing. Perchloroethylene is primarily used for specialized cleaning operations such as parts requiring cold cleaning and parts contaminated with viscous waxes.

In the mid-seventies, CFCs and trichloroethane were found to contribute to the depletion of the earth's protective stratospheric ozone layer. As a result, these cleaning solvents are being phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer (a 1992 international agreement). Originally,

the Protocol included only CFCs because of their higher ozone-depleting potential, but trichloroethane was included in the amendment of the Protocol because of the quantities used. In January 1992, NASA observed the highest level of ozone-depleting substances ever measured. These findings prompted an acceleration of the original goal of the year 2000 to a phase-out mandate on January 1, 1996. Accordingly, purchase prices and the cost of waste management for CFCs and trichloroethane have increased dramatically since the Montreal Protocol.

Methylene chloride and trichloroethylene are considered hazardous air pollutants under the 1991 Clean Air Act Amendments. The EPA requires major users to install maximum available control technology (MACT) to limit emissions. Trichloroethane, trichloroethylene, perchloroethylene and methylene chloride are classified as suspected causes of cancer in humans. Selected properties and classifications of the chlorinated solvents are shown in Table 1.1.

Synonyms and Common Names for Chlorinated Solvents
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(names in bold will be used throughout report)
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1,1,1-trichloroethane: 1,1,1-TCA, TCA, methyl chloroform

1,1,2-trichloroethylene: TCE, TRIC

perchloroethylene: PCE, PERC, 1,1,2,2-tetrachloroethylene
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methylene chloride: dichloromethane, METH, DCM, MeCl

CFC-113: trichlorotrifluoroethane, Freon, Freon TF

Table 1.1: Summary of Chlorinated Solvent Properties

Property	1,1,1-TCA	TCE	PERC	MeCl	CFC-113
photochemically reactive	no	yes	no	no	no
ozone depletor	yes	no	no	no	yes
HAP	no	yes	yes	yes	no
vapor density air = 1	4.63	4.53	5.83	2.93	6.5
evaporation rate ¹ (25C) butyl acetate=1	6	6.39	1.5-2.59	14.5	21
boiling point	72-88 C	86-88 C	121.2 C	39.4-40.4 C	47.6 C
carcinogenicity ²	suspect	suspect	suspect	suspect	no

Results from the TURI/OTA survey indicated that while most of the respondents had switched away from chlorinated solvents. When asked what motivated companies to change their cleaning systems, responses to the OTA survey indicated that 19 out of 24 companies changed because of regulations and 7 out of 24 indicated worker safety. (More than one response was possible.)

1.2 STEP 2 - LAUNCH A CAMPAIGN

Once it has been decided to pursue an alternative cleaning process, it will be necessary to obtain the support of many people at the facility. Whether the project is simply switching chemicals or substituting an entirely different process, getting buy-in from management and from those affected by the change is essential to a successful project. In the survey conducted by OTA, 8 out of 24 companies surveyed answered that “worker resistance” was an unexpected problem. This section offers some benefits of involving both management and employees and suggests some practical methods for ensuring their involvement.

Obtaining upper management support is necessary so that resources and funds are devoted to the

¹Oxsol Corporation, “Physical Properties of Oxsol and other Solvent Properties.”

²Lewis, Richard J., Sr., “Sax's Dangerous Properties of Industrial Materials,” 1992.

project. Having upper management support will motivate the employees to work on the project. Employees are more likely to support a project that they have created or at least been involved with. For projects with an environmental focus, they will also gain a sense of participation, if not ownership, in improving the company's environmental performance.

In order to obtain management support, first perform a rudimentary economic assessment including as many environmental costs as possible (see Section 4). The cleaning project may sell itself to management by avoiding compliance and waste management costs. If the project cannot be sold on its financial benefits alone, review the company's environmental statement or environmental goals and be prepared to clearly demonstrate how the cleaning project supports the statements or goals. Other potential selling points include: reduced regulatory requirements, improved worker health and safety, increased market share due to the use of green processes. Using appropriate communication channels, (e.g., formal oral presentation, informal written report), be clear and concise in presentation of the facts.

Beyond upper management support, it is necessary to gain support from other key personnel. One of the best ways to get wide-spread support is to form a project team. The most important members of the team are the people who will be expected to use the new system. It is essential to include them in the decision making process. Other important members of the team may include: production operators and supervisors, process engineers, purchasing personnel, environmental personnel, quality control personnel, sales and marketing personnel, facilities engineers and the company pollution prevention or environmental champion. One respondent in the TURI/OTA survey offered the following advice on minimizing worker resistance: "increase communication with the workers, let them know why the changes are being made and the benefits with the new cleaning product". Another respondent offered advice to be followed prior to implementation, "rigorously work out the new requirements and then train crews before implementation."

1.3 STEP 3 - ASSESS CURRENT OPERATIONS

Many experts in the cleaning field have written articles and developed series of steps to follow in order to assess the current process. The experts agree that this assessment is essential to the success of any new cleaning system. This section presents the "best of the best" for assessing the current process.

What is being cleaned? It is necessary to identify the materials of construction, the types of surfaces (rough or smooth, hard or soft), the sizes and geometries (simple or complex) of the parts that are to be cleaned.

What are the contaminants? It is necessary to identify all the contaminants that must be removed, including oil (petroleum-based, water-based, vegetable-based), grease, wax, flux, dirt and salts.

Who is applying the contaminants to the parts? If the contaminant application lies in the hands of the company that is changing the cleaning process, then that company can attempt to minimize the amount of and consolidate the number of contaminants applied. But if suppliers are applying the contaminants, companies should work with them to minimize, consolidate and find alternatives to “hard to clean” contaminants. For example, one company worked with their supplier who now uses a vanishing oil and the company did away with their entire cleaning operation. One way to accomplish this is to make contamination part of the supplier specifications. Also, examine part storage and handling practices. Parts may be getting dirty during storage and handling and changing those procedures may decrease the amount of contamination.

Why is the part being cleaned? It is tempting to quickly answer this question with “because it’s always been cleaned!” But many companies have saved money by eliminating unnecessary cleaning steps. This question deserves serious consideration.

What are the cleaning requirements? If cleaning must be done, it is necessary to know to what degree. This may be the most difficult step. Consider what happens to the parts following cleaning. The first lesson is “Clean the parts only as much as needed, no more.”

- Parts to be painted can sometimes tolerate some oil. Check with the oil supplier and paint chemists. Hot water spray washing may be enough.¹
- Parts to be assembled may only have to be oil-free to the touch. In fact, aluminum parts generally assemble better with a slight oil layer on the parts.²
- Parts to be machined do not necessarily have to be “degreased” between each operation. Centrifugal cleaning will remove most of the oil and chips and you can reclaim the oil for reuse and chips for salvage.³

Once this information has been gathered, try to *define the ideal cleaning situation* including the process (e.g., hand-wipe, immersion, spray), the equipment, the cycle-time, the amount of labor, etc. Even though the ideal situation may not be possible in a new system, it is beneficial to know exactly what is required and desired before searching for possible alternatives.

1.4 STEP 4 - IDENTIFY AND RESEARCH ALTERNATIVES

¹Smith, Robert, “Successful Aqueous Washing at Gillette”, Society of Manufacturing Engineers Parts Cleaning Technology Educational Clinic, November 8-10, 1993, pp. 2.

²Ibid.

³Ibid.

Identifying alternatives to a current cleaning process is essentially a “last” step - after eliminating all possible contaminants, after switching (or encouraging suppliers to switch) to easy-to-remove contaminants or vanishing oils, after improving handling and storage to ensure that the parts are not becoming contaminated during those processes, after establishing “how clean is clean” for the particular process to ensure that parts are not being cleaned too much, after eliminating all possible cleaning steps, then it is time to search for alternatives.

Once the cleaning needs are clearly understood, it is possible to analyze the information on alternative processes and chemistries in the context of operations. Many possible sources of information can be useful in this step. From the OTA survey, 13 of the 24 companies queried contacted vendors or private consultants for information on alternatives. TURI publishes a “Database of Cleaning Vendors,” a copy of which is included in Appendix C of this Guidebook.

A list of qualified Toxics Use Reduction Planners that are available for consulting work is available by calling the Department of Environmental Protection at (617) 292-5711. From the OTA survey, eight of the 24 did their research internally, using on-site literature, trade publications and/or databases. See Figure 1.1 for sources of information.

One source of information on alternative cleaning solvents is EPA’s Significant New Alternatives Policy (SNAP) Program. Through this program, alternatives to ozone depleting substances are identified.

Three categories of SNAP are applicable to cleaning: electronics cleaning, metals cleaning and precision cleaning. For current information on solvents that have been approved by EPA’s SNAP Program, consult the EPA website at www.epa.gov/docs/spdpublic/title6/snap/index.html.

Section 2 of this Guidebook provides descriptions, advantages, challenges and success stories of the following alternatives: aqueous cleaning, semi-aqueous cleaning, alternative solvents, mechanical cleaning and emerging or highly specialized technologies.

Periodicals

Precision Cleaning, P.O. Box 3329, Lowell, MA 01853-9975

Micro contamination - Ultra clean Manufacturing Technology and Management, P.O. Box 21651, St. Paul, MN 55121

Plating and Surface Finishing - Journal of the American Electroplating and Surface Finishing Society, Inc., 12644 Research Parkway, Orlando, FL 32826

Conferences

Precision Cleaning (annual)

Mr. Clean (semiannual)

International CFC and Halon Alternatives (annual)

AESF/EPA Pollution Prevention and Control (annual)

International Workshop on Solvent Substitution (annual)

Web Sites

TURI’s Surface Cleaning Laboratory <http://www.cleaning.org>

Research Triangle Institute <http://www.clean.rti.org>

EPA <http://www.epa.gov>

1.5 STEP 5 - INITIAL SCREENING OF ALTERNATIVE CLEANERS

The initial screening of alternative cleaners is where the process of moving away from the old system begins. So far, the team has been created and current operations have been assessed. The research is complete and the options have been chosen. Now it is time to narrow the options. It would not be practical to perform a complete economic analysis on every cleaning option. To help limit the number of alternatives to be evaluated, ideas of “things to consider” are provided. Four categories are considered: health and safety, regulatory and waste, “ease of conversion” or convenience and cost. From these ideas a unique set of criteria can be developed by the team for further screening of alternative chemistries and processes.

1.5.1 Health and Safety Considerations

The employees’ health and safety should be of primary concern when screening potential alternatives. A *current* (less than two years old) Material Safety Data Sheet (MSDS) should be consulted to determine exposure limits. Information on the MSDS is limited to hazardous components present in concentrations greater than one percent (except for carcinogens which must be reported if present in concentrations greater than 0.1 percent). State regulated chemicals (i.e., Massachusetts TURA chemicals) are not required to be listed specifically. If the information provided on the MSDS is scarce, the chemical manufacturer should be contacted. If they are unwilling to provide assistance on health and safety issues, another vendor should be considered.

Some specific points to study:

- Is the new chemistry flammable? If the flash point is below 140°F extreme caution should be used in implementing the chemistry and specialized cleaning equipment may be necessary.
- Will personal protective equipment (PPE) be necessary for the operators?
- Will ventilation be necessary for the cleaning area?
- What are the threshold limit values (TLVs) for exposure?
- What OSHA standards apply to the new cleaning system?
- Will safety training for the operators need revision?

1.5.2 Regulatory and Waste Considerations

Ideally the new system will reduce regulatory reporting and permitting at the facility. However, different processes prompt different regulatory concerns. Even though the alternative process may reduce the volume of waste, some type of waste will result. Close attention should be paid to the ultimate fate of the byproducts of cleaning processes. When comparing alternatives, the following should be considered:

- What are the regulatory implications with regard to wastewater discharge? For example, industrial wastewater discharges to septic systems are prohibited in Massachusetts.
- Will the wastewater include metals?
- Will there be a change in regulated air emissions?

- Will there be a change in the reporting status under EPCRA or TURA?
- Will the volume of solid waste change? Will this waste be hazardous?
- What new permits may be required if this cleaning system is installed?
- Do OSHA standard apply?
- Will the new system require a change to the contingency plan?

1.5.3 Convenience Issues

Ideally one would like to switch to a cleaning system that will cause minimal disruption to their process before, during and after the conversion. This system would drop in easily, require minimum down-time for installation, and require little operator re-training. While this may be entirely possible, the following questions should be raised:

- Will the operators be resistant to change? What can be done to minimize resistance?
- Is the substrate to be cleaned compatible with the chemistry that is proposed?
- Will the new cleaning process change upstream or downstream parameters of the production process?
- Are case studies available that document the success of other companies in implementing this type of cleaner/cleaning system?
- Can the cleaning effectiveness be demonstrated at vendors' customers' facilities and is a visit to a facility using the cleaning system possible?
- What maintenance will be required for the new equipment?

1.5.4 Cost Considerations

Ideally, the new process will have a lower operating cost than the current process, thus generating savings that offset the capital cost of the new process. Here are some points to consider:

- What is the capital cost of the new process?
- Can the existing equipment be used with little or no retrofitting?
- Are any building or floor plan changes necessary?
- Will the new process require more or less labor than the old process?
- What utilities are required?
- What raw materials are required?
- Will a cost savings be realized due to decreased environmental reporting and permitting?
- Can a decrease in liability or insurance costs be quantified?

Initial screening is an important step. Performing a complete initial screening will save time down the line by limiting the number of choices for more thorough evaluation. This is not a complete list of items to consider. It is intended to give a starting point for generating process specific screening questions. A more comprehensive list of questions is included with the EPA's Solvent Alternatives Guide (SAGE) software (phone 919-541-0800). A "Process Conversion Checklist" is available which includes six pages of questions similar to those posed here.

1.6 STEP 6 - TESTING AND IMPLEMENTING THE ALTERNATIVES

This section provides a generic protocol for benchscale testing cleaning alternatives and suggestions for pilot-scale evaluations. This section also describes TURI's Surface Cleaning Lab services.

1.6.1 Benchscale Testing

No matter which alternative(s) seem(s) most promising at this stage of the conversion, benchscale testing is necessary to define the parameters associated with the use of a new cleaning system. Figure 1.2 outlines the standard protocol for evaluating alternative cleaning chemistries and processes. Initially, a baseline "clean" must be established as a reference against which the alternatives can be tested. After a company has thoroughly assessed their current operations (see Section 1.3) some idea of the necessary or adequate level of cleanliness is understood and a measurement for the level of cleanliness can be determined. Next, a contamination protocol should be followed where a representative or actual part is contaminated, aged according to actual process conditions and some measurement is taken (e.g., gravimetric analysis) to determine the contaminant loading. Then the cleaning protocol (including rinsing and drying if

Figure 1.2: Cleaning Protocol

Establish Baseline "Clean"

- Identification of Substrate for Testing: actual or representative parts or materials.
- Standardized Cleaning Procedure: must be performed prior to contamination step in order to establish a baseline clean (e.g., clean in a commercial liquid detergent at a certain temperature and agitation).
- Analysis of "Cleaned" Substrates: determine level of cleanliness of substrate before contamination.

Contamination Protocol

- Designate Contaminant: cutting oils, lubricants, greases, coolants, particulates, chips and fines, oxidation products, fingerprints, waxes, aqueous-based, synthetic, petroleum-based, natural products.
- Contaminant Application: should be applied in a manner and magnitude that mimics actual situation (e.g., paint brush, spray or wipe-on application of machining fluid to a metal part).
- Drying Process: dry/age in air or dry/process at elevated temperature depending on actual situation.
- Analysis of "Contaminated" Substrate: determine level of cleanliness of substrate following contamination.

Cleaning, Rinsing, and Drying Protocol

- Select Alternative Cleaning Process or Chemistry: from technical literature, product bulletin, MSDS, manufacturer, distributor. Select rinsing and drying processes if necessary.
- Select Appropriate Number of Tests for statistical validation and design of experimental trials based on the number of experimental variables chosen.
- Select Variables to Investigate: for example, for aqueous cleaning, wash time (1 to 15 minutes), wash temperature (70-190°F), concentration of cleaning solution (start with manufacturer's recommendations).

appropriate) is followed for each situation tested.

Company in-house testing

Some companies conduct in-house testing of alternative cleaning systems. The advantage of using company resources and personnel is the ability to directly manage the testing process and to mirror production conditions as closely as possible. The disadvantages include the time and labor involved. In addition, companies may not have the expertise or equipment to conduct testing in-house.

Vendors

Many vendors of cleaning equipment offer bench-scale testing services. Vendors will recommend the equipment model, features and operating parameters that should be appropriate for a particular situation. It would be beneficial to know everything about the desired cleaning requirements before arranging testing with a vendor. If aqueous or semi-aqueous processes have been chosen, the vendor search can begin with TURI's Vendor Database. (See Appendix C.)

TURI Surface Cleaning Lab

TURI's Surface Cleaning Lab (SCL) is an industrial lab that routinely performs application-specific research on aqueous and semi-aqueous cleaning, rinsing, and drying processes with a focus on metal finishing and metal parts fabrication. More specifically, the SCL outlines cleaning options for customer situations, performs testing on actual dirty parts or standardized test coupons, evaluates commercially available aqueous and semi-aqueous cleaners, and helps define cleaning specifications. The services are free-of-charge to Massachusetts companies.

The SCL has the following cleaning, rinsing and drying equipment available for testing purposes:

- three 5 gallon ultrasonic tanks (25, 40 and 68 kHz)
- a 5 gallon air-agitated, temperature-controlled immersion tank
- two low pressure spray washers
- two 16 gallon drum-mount pressure spray washers
- two 5 gallon heated rinse tanks
- deionized water and tap water supplies
- ambient air knives
- convection and vacuum ovens
- infrared heat lamps
- portable heat guns

The Lab has over 200 aqueous and semi-aqueous cleaners and a wide selection of test coupons such as stainless steel, brass, copper and aluminum. The Lab also stocks representative soils and process fluids for use in contaminating the coupons.

A company requesting services from the Lab is asked to complete a Test Request Form (See Appendix D.) that documents the items discussed in Section 1.3: Assess Current Operations. A site visit may or may not be necessary depending on the request. Beyond this, no two applications are identical and therefore, the lab tests are modified as each application necessitates. There are four general stages of testing at TURI's SCL: 1) Compatibility and "Lift" Studies, 2)

Temperature and Concentration Studies, 3) Mechanical Energy Studies and 4) Actual Product Cleaning Studies. Brief descriptions of these four stages follow.

Stage I: Compatibility and “Lift” Studies

With the information obtained from the Test Request Form and the site visit (if necessary), Lab staff consult their database of successful test results, cleaner reactivities and compatibilities with substrates, and chemical information (e.g., material safety data sheets and chemical handbooks) and choose cleaner formulations with which to begin testing. Initial testing typically consists of “lift” studies where a few drops of each cleaner are placed on grossly contaminated coupons. Cleaners that cause a visual “lifting” of the contaminant from the surface are selected for further testing. These tests are performed at ambient conditions with no addition of mechanical energy. Because this is a quick test to select cleaners for more rigorous testing, the Laboratory Evaluation Protocol shown in Figure 1 is not strictly followed at this stage of testing.

Stage II: Temperature and Concentration Studies

The next stage of testing is a chemical comparison of the cleaners that were selected in Stage I. The chemical manufacturers’ recommendations for temperature and concentration are followed and some low source of mechanical energy is added for a period of time. The type of mechanical energy chosen is based on the Lab staff’s recommendation for the particular application; it must be low energy and constant throughout the testing otherwise differences in chemistries cannot be seen. If coupons are used in the testing, gravimetric analysis is often used to compare the performance of the chemicals with regard to percent contaminant removed.

Stage III: Mechanical Energy Studies

From the results of Stage II, the best performing chemistry or chemistries are tested in order to optimize the use of mechanical energy. Factors such as cost, space availability and any other criteria, such as training requirements, that the company indicates are important are considered in this stage.

Stage IV: Actual Product Cleaning Studies

Testing, at the optimal conditions determined in the previous stage, may be performed on actual company parts. Recommendations from the results obtained are made to the client company.

1.6.2 Pilot-Scale Evaluation

Several routes are available at this stage in evaluating a new cleaning process. The route chosen depends on the particular situation. It is very important not to skimp on this stage. Pressed for time, many companies skip this evaluation only to regret it when faced with unforeseen problems that could have been solved in a pilot-scale evaluation. Thorough pilot-scale evaluations will result in an easier transition to the new cleaning system. This evaluation can be conducted in the following ways: 1) leasing or renting equipment, 2) pilot-scale testing with a vendor, 3) viewing the equipment of the vendor’s customers (arranged by the vendor), and 4) using local contract cleaners. Thorough sampling and testing of waste streams should be completed at this stage of the evaluation.

1.7 STEP 7 - FINANCIAL CONSIDERATIONS

1.7.1 Introduction

The financial analysis is an important step in developing a complete picture of the feasibility of a project. This section describes the process of performing a basic financial analysis, with particular focus on the importance and process of gathering complete cost information. It provides an overview of how to use cost information to assess the financial implications of a project using different measures of profitability but does not present detailed descriptions of the actual calculations. For those who are interested in the calculations, further information including a sample problem and blank worksheets is available in Section 4 of the guidebook. Finally, this section discusses benefits of cleaning process conversion that are difficult to quantify but may have significant long-term value.

1.7.2 The Cost/Benefit Analysis

Performing a financial analysis can be broken into four steps. The most important step for the cleaning process conversion team and the first step in this analysis is the collection of complete cost information. The three steps that follow cost collection may actually be performed by the financial staff and thus will receive little attention in this section. These are, in order, determining incremental cash flows, applying measures of profitability, and interpreting the results.

1.7.3 Collecting Cost Information

During a financial analysis two types of cost information must be collected: the current process operating costs and the proposed project costs. Proposed project costs are often based on estimates from vendors and may not be difficult to obtain. On the other hand, collecting current process costs can be a time consuming exercise. The team should understand that the more time spent collecting cost information the more accurate a picture that will be generated about the current and proposed cleaning processes. This is not a half-hour project that should be taken lightly. Frequently new processes are beneficial by generating savings within the easily overlooked or “hidden” costs. A rough worksheet that includes only direct labor, chemistry and capital equipment costs does not present an accurate accounting of the expenses generated by the current cleaning system. If the current cleaning system is not completely characterized, the proposed cleaning system may be unfairly discarded on the basis that it appears to be too expensive. The team should do its best find all of the costs for the current and proposed projects.

Sources of Cost Information

Unfortunately, cost information will not be neatly stored in one central location within a facility. In fact, some of this information may not be recorded anywhere. Multiple sources will be important to utilize during this step. These sources include, but are not limited to the following:

Interviews with plant personnel. These sources should be able to provide a variety of information. Operators are the best source for determining labor hours associated with the current cleaning process. Environmental personnel should be able to estimate the time spent dealing with various tasks for the current system such as waste management, employee training, permitting and regulatory compliance. Facilities personnel should be able to provide information such as utility costs.

On-Site Records. Purchasing records can provide costs of chemistry, costs of safety equipment, and other purchases associated with the current system. Payroll records may be useful for connecting an hourly labor rate with the plant personnel involved in the cleaning operation. General accounting records may be a good resource for other costs that are difficult to locate.

Logs of Activities and Material Usage. Some equipment may have a daily, weekly or monthly usage log that documents chemical additions to the cleaning system. Operators who devote time to cleaning on a part-time basis may have logged actual hours spent on the process. There may be logs that document running time for the cleaning equipment.

Receipts and Invoices. These may fill in the gaps in information that is unavailable from sources such as purchasing and accounts payable.

Vendors. Vendors are an important source for determining cost information for the proposed cleaning system. There may be multiple sources here as well. The cleaning equipment may be produced by one company and the chemistry be another (this is fairly common). Required safety equipment for the proposed system will most likely be purchased from a third source. Installation may be handled by outside sources as well.

This first step of a cost/benefit analysis will probably require the most time. Barriers to collecting complete cost information are presented in the following section.

Challenges to Collecting Complete Cost Information

As in the case of the *Sources of Cost Information*, this is not a complete set of challenges. Each situation will present unique dilemmas that will be dealt with on a case by case basis. Some common problems are:

Finding the Information. It is likely that cost information will be scattered across the organization. Finding every detail will take some time-consuming detective work on the part of the project team. Some information may not be available regardless of how much time is spent searching for it.

Coordinating the Sources. All of the necessary information may exist within the facility. There will still be some coordination necessary to have the information returned to the team in a usable format and in a timely fashion. Hopefully the dynamics of the cleaning conversion project team are such that the individual members are self-motivated and work well together. Communication is key and “buy-in” by the team is important to ease this data collection.

Poor Record-Keeping. Some companies have little or no material tracking. Material is used as needed, and purchased when depleted. In some cases, daily usage may be extremely variable. For instance, in hand-cleaning processes, operator technique plays a large role in cleaning material usage, especially with volatile chemistries. Thorough record-keeping is absolutely necessary for a complete understanding of a cleaning process, and companies that do not do this will benefit from instituting procedures for material tracking.

Operator Reluctance. Some operators may not appreciate giving details about how they do their job. To them, secrecy guarantees job security. If they think that the new cleaning system is going to replace them on the shop floor, there is little chance they will be cooperative when the time comes to gather cost information. Again, this leads back to communication and it emphasizes the importance of including key players on the project team, from the beginning! Successful conversion requires buy-in not only from management, but from the people using the system every day. In the end, they are the ones who will make the new cleaning system work (or make it not work, if they so desire).

Types of Costs

In order to calculate incremental cash flows, two types of costs are required. The first type, capital costs, represents the one-time costs associated with purchasing, permitting, installing and training for the new system, and the one-time costs associated with disposal of the old system. These costs are fairly conventional and generally easier to capture than the second type of costs, the recurring costs.

The recurring costs represent all of the costs associated with the annual running and maintenance of the system. In addition to chemicals, direct labor, and utilities, these costs also include waste management, safety training, insurance, maintenance, regulatory fees and paperwork. Finding these costs will probably take some time. They are numerous, and they are generated throughout the facility. Hidden recurring costs abound, some of which may be found in Figure 1.4.

Figure 1.4: Potentially Hidden Costs¹

<u>Regulatory</u>	<u>Up-Front</u>	<u>Voluntary</u>
Notification	Site Studies	Community Relations
Reporting	Site Preparation	Monitoring/Testing
Monitoring/Testing	Permitting	Training
Studies/Modeling	R&D	Audits
Remediation	Engineering/Procurement	Qualifying Suppliers
Record Keeping	Installation	Reports
Plans		Insurance
Training	<u>Conventional Costs</u>	Planning
Inspections	Capital Equipment	Feasibility Studies
Manifesting	Materials	Remediation
Preparedness	Labor	Recycling
Protective Equipment	Supplies	Environmental Studies
Medical Surveillance	Utilities	R&D
Environmental Insurance	Structures	Habitat and Wetland Protection
Financial Assurance	Salvage Value	Landscaping
Pollution Control Equipment		Other Environmental Projects
Maintenance	<u>Back-End</u>	Financial Support to Environmental
Repair	Closure/Decommissioning	Groups and/or Researchers
Spill Response	Disposal of Inventory	
Storm water Management	Post-Closure Care	
Waste Management	Site Survey	
	<u>Contingent Costs</u>	
Future Compliance Costs	Remediation	Legal Expenses
Penalties/Fines	Property Damage	Natural Resource &
Response to Future Releases	Personal Injury Damage	Economic Loss Damages
	<u>Image and Relationship Costs</u>	
Corporate Image	Relationship with Workers	Relationship with Lenders
Relationship with Customers	Relationship with Suppliers	Relationship with Regulators
Relationship with Investors	Relationship with Professional Staff	Relationship with Host Communities
Relationship with Insurers		

¹Introduction to Environmental Accounting as a Business Management Tool, U.S. EPA, 1995.

Once complete cost information has been collected, incremental cash flows may be generated. More information on the specifics of these calculations is included in Section 4 of this Guidebook.

1.7.4 Measures of Profitability

There are different measures of profitability that may be applied to the financial analysis of a cleaning process conversion. The most common, and the only three that will be discussed in this section, are simple payback, internal rate of return (IRR), and net present value (NPV). This discussion will be brief and will not include information on how these calculations are made. A sample problem with a more in-depth look at these measures is located in Section 4.

Simple Payback

Simple payback is a commonly used measure of profitability in financial analysis. It is useful for a rough-cut first analysis of a project to see if the project should be considered for further study.

The advantages of simple payback include the fact that it is easy to understand and it is simple to calculate; the total cost of the project is divided by the annual savings it generates. This number indicates how many years it will take before the project pays for itself.

Unfortunately, simple payback does not account for the “time value” of money. Additionally, simple payback does not measure the scale of gain that a project may provide and therefore, projects cannot easily be ranked using this financial indicator. See the text box for an example of this.

Net Present Value and Internal Rate of Return

NPV and IRR are financial indicators that require a more detailed calculation. They are, however, the preferred measures of profitability for capital investments required by a cleaning system conversion. They should be used for the final analysis of the few options that a manufacturer is considering. NPV and IRR should not be calculated for every possible alternative found during the research phase of this project.

The advantages of calculating NPV and IRR include the fact that these financial indicators consider the “time value” of money. That is to say that the value of the project will be represented by a figure in today’s dollars (for NPV), or percent return generated by the project (for IRR). In addition, these financial indicators measure the “risk adjusted” value added to a company. This is because the NPV and IRR calculations are based on a discount rate which is a rate that, among other things, factors risk into the equation.

The disadvantages of computing NPV and IRR are that they require more information and the calculations are more intensive than for simple payback. The company needs a discount rate for this calculation, and cash flows need to be estimated over the life of the project.

More detailed discussion on these calculations and a sample spreadsheet are included in the Section 4 of the Guidebook.

The following is an example of using simple payback and net present value assuming a five year lifetime and a 10% discount rate.

Project A costs \$5,000 and generates \$10,000 in annual after tax savings. Simple payback on the project is 6 months. Project B costs \$50,000 and nets \$25,000 in savings annually. Project B has a payback of 2 years. Using the NPV formula, Project A, with the shorter payback, is worth \$32,908 in today's dollars. Project B, despite a payback that is four times greater than Project A, is worth \$44,770 in today's dollars. Clearly Project B is shown to contribute more value to the company when both projects are compared using NPV.

1.7.5 Other Benefits of Process Conversion

There are some benefits that will be realized by modernizing equipment to which it may be difficult to assign a monetary value. Even so, such benefits should be considered in a project assessment even if they are not directly factored into the financial analysis. Some of these benefits are:

Improved Employee Health and Safety. Reduced employee exposure to dangerous solvents or other toxic materials may have a large financial impact on a company. A cleaner working atmosphere may reduce productivity losses from sick-time. Reducing the risk of toxic over-exposure will reduce the risk of potential future health claims against the company. These economic benefits may be hard to tabulate.

Lower Maintenance. Older equipment may require more frequent maintenance due to wear and tear. It may be difficult to compare maintenance costs with a potential replacement system, especially if nobody within the organization has experience with the new technology. There may be a savings here to consider, however.

“Green” Marketing. While this may be especially difficult to predict, a new cleaning system may open doors into “green” markets and thus generate more business for the company. It may be key to maintaining or creating a relationship with a large company that wants its suppliers to be environmentally responsible.

Efficient Chemical Usage. The new system could be very efficient because it is designed to work with the new alternative solvents. While these chemistries may be very expensive, annual usage could be much lower when compared to current chemistry requirements. Predicting usage for the new system may be difficult if a similar system cannot be found for comparison.

Improved Production Rates. Some new cleaning processes may be more effective at removing the soil. This is because many products are now engineered for specific applications - they do not use “one size fits all” approach that traditional solvents have used. Precise changes in production rates due to faster cleaning may be difficult to tabulate during the financial analysis. Reduction in reject rate and rework may be easier to assess.

Reduced Regulatory Burden. If the new system completely exempts the company from environmental regulatory reporting, calculating savings should be fairly straightforward. However, if reporting and training are not completely eliminated, the reduction may be difficult to compute. It may also be difficult to calculate the value of other activities that can now fill the time made available.

Lower Future Liability. If the insurance company reduces rates for liability based on the elimination of the current toxic chemical, calculating savings is easy. If there is no insurance break, it may be difficult to assign a monetary value to this savings. Perhaps reducing the risk of a

single, multi-million dollar lawsuit against the company, or reducing the risk of a clean-up is enough to convince them to switch to a safer process. Generators of hazardous waste are responsible for their waste streams from “cradle to grave.”

Reduced Likelihood of Enforcement and Enforcement Costs. Eliminating the use of a regulated substance eliminates the potential for fines due to the misuse of the substance. In addition, the EPA and many state environmental agencies have new programs to separate companies that go beyond compliance from those that don’t make a commitment to environmental performance. A switch to a less toxic system can result in a reduced potential for receiving an inspection and also increases the possibility of receiving penalty mitigation in the case of violations.

These are some of the considerations that may be inconvenient or difficult to include in the financial analysis of the alternative cleaning system. There are others as well. Even if numbers cannot be assigned to these benefits, some discussion of them should be included in the overall analysis of the cleaning system.

1.7.6 Sources of Further Assistance

The previous section scratches the surface of a complete financial analysis. It is probably not the responsibility of the project team to make every calculation mentioned above. It is, however, the team’s responsibility to help collect the cost data and to spend some time ensuring that the data is as complete as possible. Assistance is available from a number of resources. The most obvious and first resource to contact is the company’s in-house accounting staff, where available. In addition to this resource, there is software available that will calculate these measures of profitability. The Tellus Institute, of Boston, Massachusetts, has produced a spreadsheet called “P2 Finance.” In Massachusetts, this software is available free of charge from the Office of Technical Assistance (OTA). OTA also has an analyst on staff to assist Massachusetts companies who would like further information or assistance on the financial analysis of pollution prevention projects. Finally, the Northeast Waste Management Officials’ Association (NEWMOA), has produced the training manual, “Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects.” NEWMOA may be reached at 617-367-8558. OTA may be reached at 617-626-1060, and the phone number for the Tellus Institute is 617-266-5400.

Section 4 contains a sample case study and a more detailed financial discussion, including blank worksheets.

1.8 STEP 8 - REGULATORY ANALYSIS¹

The importance of knowing which environmental regulations apply to both the current and the alternative cleaning systems cannot be overstated. Decisions to change cleaning systems or exclude alternatives from further study may be made from the regulatory analysis alone. For example, when the Labeling Law required that products cleaned with certain ozone-depleting solvents (e.g., trichloroethane) be labeled to reflect the use of ozone depleting substances, some companies simply refused to use the solvent rather than bear the cost and stigma of the label. Knowing the current laws regarding cleaning chemicals being considered as alternatives may save the effort of evaluating them for technical feasibility only to find out that their use is cost prohibitive due to the regulatory requirements. In the same manner, it is important (albeit more difficult) to have some sense of proposed regulations prior to investing too much time into the evaluation of alternatives. If a company is considering hydrochlorofluorocarbons (HCFCs) for example, it is important to know that these are transitional products that will be banned within 10 to 15 years.

As discussed in Section 1.7, process decisions should be made, in part, based on the cost of compliance with environmental regulations. Calculating current and potential regulatory cost is instrumental in preparing a true picture to compare the costs of the current system and the alternatives being considered. If a company is still using a chlorinated solvent for example and is now subject to maximum available control technology (MACT) standards, the cost of compliance for that system may now be much higher than a few years ago making the alternatives more attractive.

A complete regulatory analysis considers all of the potential wastes (e.g., spent solvent, tank bottoms, oily waste) and emissions (to air and water) from a process. The waste streams and emissions from cleaning systems should be completely characterized to determine applicability of hazardous waste regulations. If any waste material meets definitions of ignitability, corrosivity, reactivity or toxicity, or if it is listed as a hazardous waste in Massachusetts regulations, it is considered hazardous and should be handled, stored and transported in accordance with these regulations.

Some cleaning chemicals may be hazardous while being used. Refer to the Material Safety Data Sheet (MSDS) for more information on the hazards of the material as well as health and safety precautions that should be observed during use of the material.

For air regulations covering cleaning systems, it is important to know the regulatory status of the chemical being used. First, is the chemical a volatile organic compound (VOC) or a hazardous air

¹This is not a substitute for reading the regulations. To ensure compliance, the full, updated text of the rules should be consulted.

pollutant (HAP)? Figure 1.5 provides the sources of lists to aid in determining a chemical's regulatory status. Note that there are both federal and state lists for VOCs. Second, how much is emitted or used? This number must be calculated to determine if regulatory thresholds have been (or will be) exceeded. For mechanical cleaning systems, the emissions of particulate matter could exceed threshold quantities and require permitting. (Refer to 310 CMR 7.02 and 7.12.)

For cleaning systems resulting in an aqueous discharge, there are four possible disposal routes: 1) direct discharge to sewer, 2) direct discharge to surface water, 3) sending off-site as hazardous waste, and 4) discharge to on-site pretreatment. For direct discharges, appropriate permits must be obtained from the publicly-owned treatment works (POTW) and possibly from DEP to discharge to the sewer. Permits from EPA and DEP are required for discharge to surface water. Permits could require limitations on organic material, acidic or alkaline contaminants, suspended solids, metals, or other material that could cause a biological or chemical oxygen demand.

Worker health and safety regulations must also be considered when evaluating options for a cleaning system. A chemical's material safety data sheet is an important reference in determining potential health and safety issues and in planning for the safe use of the chemical.

A federal law, the Emergency Preparedness and Community Right-To-Know Act (EPCRA), and a state law, the Massachusetts Toxics Use Reduction Act (TURA), may also apply to cleaning chemicals if they appear on the corresponding lists and if thresholds are met. See Section 5 for a more detailed description of these requirements.

DEP listing of VOC exemptions - Emissions Statement Package 310 CMR 7.12, or online at www.magnet.state.ma.us/dep
EPA listing of VOC exemptions - 40 CFR 51.100
EPA listing of HAPs - Emissions Statement Package 310 CMR 7.12
EPCRA chemical list - Form R package, available from the EPCRA hotline at 800-535-0202
TURA chemical list - From S package, available online at the above address
MSDS - available from supplier, provides flash points, TLVs for OSHA regulations, reactivity, pH, %VOC

To aid in identifying applicable regulations, a regulatory matrix is presented in Section 5. The matrix identifies potentially applicable regulations for each cleaning alternative described in Section 2. For additional help in this area contact the Office of Technical Assistance at 617-626-1060, the appropriate regulatory agency or an applicable trade association.

1.9 STEP 9 - AVOIDING PROBLEMS

As mentioned in the Introduction, respondents in the TURI/OTA survey offered problems with their alternative cleaning systems or barriers to their implementation. These were combined into four major groups. The problems and suggestions for preventing or correcting them follow.

1.9.1 Ineffective Cleaning

One way to avoid the problem of ineffective cleaning is to perform *thorough* bench- and pilot-testing before implementing an alternative system. This means working to consolidate and minimize contaminants and testing *all* the substrates and contaminants in the proposed system, prior to purchase. Unfortunately this takes time; but the time is well spent if problems are avoided before installation. If the system is already in place and the results are unsatisfactory, a change of temperature (wash or rinse), time (wash or rinse), agitation (wash or rinse) or cleaner type or concentration may correct the problem. A change in the soil or soiling conditions, presoaking with spent cleaner or the addition of a mechanical cleaning step may be necessary.

1.9.2 Cycle Time or Drying Time

Once again, thorough evaluation of an alternative will help to avoid this problem. If cycle time is critical for the application, this criteria must be defined early in the options evaluation phase. Also, be certain to design the system for possible production rate increases. If the system is already in place and the aqueous system has too long a cycle-time, changes in temperature (wash or rinse), time (wash or rinse), agitation (wash or rinse) or cleaner type or concentration may correct the problem. If the problem lies in the drying stage, depending on the drying system used, increasing air flow or temperature may shorten the drying time.

1.9.3 Cost

Performing a total cost assessment on the current and proposed systems may help to justify the cost of the new system. Obtaining the actual costs of using and disposing of chlorinated solvents is important as a baseline for comparison with a new system. If the current system is a water-cooled vapor degreaser, do not neglect the purchase and disposal costs of the water. A TURI case study of solvent substitution by aqueous cleaning at Parker Hannifin Corporation revealed a total project payback period of approximately one year due mostly to savings in water purchase and sewer costs. In addition, reuse of the bath water through bag or cartridge filtration, skimming or coalescing or reuse of the water *and cleaner* using a membrane filtration process may improve the cost performance. Shopping around is also a key to cost savings when purchasing an aqueous system.

1.9.4 Residue

Once again, avoiding this problem requires a thorough evaluation during bench- and pilot-testing. Anhydrous silicates in the cleaner may cause inefficient rinsing and result in a residue. TURI or the vendor can suggest a cleaner without anhydrous silicates. Poor quality rinse water may cause a residue. Water softeners may alleviate this problem but can result in discharge problems. Deionized water may be necessary. Additional suggestions for correcting or avoiding this problem are offered in Section 3.2 on Drying.

Figure 1.6 provides a summary of twelve statements of advice from companies that have implemented alternative cleaning systems.

**Figure 1.6: Twelve “Statements of Advice”
(from companies that have implemented Alternative Cleaning Systems)**

- Locate a reputable supplier of chemistry to train employees and supply the product.
- Test all materials and soils because assumptions may return to haunt you.
- Look into a large variety of part washers.
- Increase communication with workers about why the changes are being made and the benefits with the new cleaning product.
- Place a greater emphasis on cycle time when evaluating options.
- Buy all equipment up front, while motivation and incentive are still there.
- When purchasing equipment, increase the capacity of part washers.
- Rigorously work out the new requirements and then train crews before implementation.
- Develop safe-guards against problems, i.e., the staining of the substrate, in the early stages of implementation.
- Track costs throughout the conversion process.
- Obtain customer input up-front in order to prevent any barriers down the road.
- More consultation with OTA, vendors, or TURI.

SECTION 2: ALTERNATIVE CLEANING TECHNOLOGIES

2.1 INTRODUCTION

This section provides descriptions, advantages, challenges and success stories of the following alternatives: aqueous cleaning, semi-aqueous cleaning, alternative solvents, mechanical cleaning and emerging or highly specialized technologies. Vendors of these chemistries and equipment can be found in Appendices C and E.

2.2 AQUEOUS CLEANING

Aqueous cleaning typically combines cleaning, rinsing, drying, and recycling, treatment or disposal with a method of moving parts through the system. Aqueous cleaning uses water and additives such as builders, surfactant, corrosion inhibitors, and chelators. Basic information on these additives and their purposes is provided in the following section.

2.2.1 Aqueous Cleaner Additives

Sometimes deionized water (with no chemical additives) is used to clean parts (e.g., printed wiring boards). This cleaning system relies on mechanical energy, such as spraying and the solvent action of water. Most often, aqueous cleaners are formulated with additives which make the cleaning systems more effective. This section describes some of these additives and their functions.

Builders: Often the main ingredient of the aqueous cleaner, builders are inorganic salts that provide alkalinity and buffering capacity to aqueous solutions. The most common builders are hydroxides, borates and silicates. Builders assist in softening, dispersing and saponifying contaminants.

Surfactant: Surfactant, or surface acting agents, are the main workhorse of the aqueous solution. Nonionic surfactant are the type of surfactant most widely used in metal cleaning. Nonylphenol ethoxylates and primary alcohol ethoxylates are two groups of nonionic surfactant. Combinations of surfactant may be used to achieve one or more of the following functions: wetting, dispersing, emulsifying, displacing.

Inhibitors: The most popular type of inhibitor used in aqueous cleaning solutions is a rust inhibitor. Ferrous metal parts can rust after being cleaned in water. The rust inhibitor leaves a thin film on the part which prevents a reaction between oxygen and the part surface. Inhibitors can also be used to prevent the attack of sensitive metals (e.g., brass, copper, aluminum, zinc) at elevated pH's and temperatures. Inhibitors may be used in cleaning or rinse stages. Silicates are the most common inhibitor. Inhibited aqueous solutions require special attention in the rinse and dry stages to avoid spotting.

Chelators and Sequestering Agents: Chelators such as ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetate (NTA) are used to keep metal ions in solution. Sequestering agents are used

to remove unwanted ions such as hard water ions and metal ions. Sequestering agents will soften water and reduce the potential for cross-plating when multiple substrates are used. The choice of a chelator or a sequestering agent depends on the type of wastewater treatment system used.

Saponifiers: Saponifiers are highly alkaline cleaners which convert fatty acids and glycerides to water soluble soaps. They are used most often in removing rosin-based fluxes, buffing compounds and fatty oils and greases. Additives such as monoethanolamine, glycol ethers, hydrogen peroxide and alcohols may be added to alkaline solutions to help saponification. Saponification will lower the life of a cleaning bath and cause foaming in moderately agitated systems.

Water based cleaning systems rely on mechanical action to enhance cleaning. Generally, this involves movement of the cleaning solution (using spray, spray under immersion, turbulence, or ultrasonics), movement of the parts to be cleaned (using tumbling or vertical oscillation), wiping, scrubbing or a combination of these methods. One of the most common methods of supplying mechanical energy is by use of a spray nozzle washer. The size and shape of the work piece seldom influences the chemistry of aqueous cleaners. It may determine the method of agitation and handling techniques. Part orientation and material handling must be considered when designing an aqueous cleaning system.

To obtain a wall chart from EPA titled "Aqueous and Semi-Aqueous Solvent Chemicals: Environmentally Preferable Choices," contact the hotline at (202) 554-1404 and ask for document number EPA-743-B-96-001.
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Aqueous cleaners can remove oil by forming oil/water emulsions or by displacing oil. Emulsifying aqueous cleaners remove oils from parts and form tiny droplets throughout the solution whereas non-emulsifying cleaners float oils to the surface of the cleaning bath. Non-emulsifying cleaners require more agitation but can easily be recycled. Oils that accumulate on the surface of the cleaning bath can be removed using oil skimmers, vacuuming, or oil absorbing pads. Depending on the surfactant, emulsions may be broken by adding polymers, lowering the temperature or adding agitation. If the emulsion is not broken, dispersed or emulsified oils may require the use of membrane filtration (microfiltration or ultrafiltration) for separation from the cleaning bath.

Though potentially expensive to install, aqueous cleaning systems may result in saving money through lower chemical costs and reduced waste management and environmental compliance costs.

Typical Applications

- Removal of scale, rust, oil and grease
- Best for inorganic soils (oxides, salts, polishing compounds, acid flux)

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Can result in cost savings due to decrease in chemical purchase and waste disposal.	Three step process compared to one step in traditional solvent cleaning.
Safer for the environment and employees than chlorinated solvents.	Ultrasonics, high solution temperature, or agitation may be necessary to achieve required cleanliness.
Waste stream can be recycled using skimming, coalescing, membrane filtration.	Corrosion or water spotting may be a concern, since some parts may not be dried quickly enough to avoid oxidation from moisture.
Many suppliers; competitive marketplace.	May require additional floor space.
Excellent rinsing characteristics with little or no residue.	High initial capital cost.
Aqueous cleaners have a broad range of uses and water dilution ratios.	May require more time than solvent cleaning.
Custom chemicals can be formulated.	Disposal of spent solutions.

2.3 SEMI-AQUEOUS CLEANING

Semi-aqueous processes fill the niche between aqueous and solvent cleaning. They can either be described as low vapor pressure solvents that are rinsed or diluted with water, or chemistries that are emulsified in water using surfactant and used in the same manner as aqueous cleaners. These cleaning agents can be separated into two categories. The first, *water immiscible cleaners*, is based on petroleum hydrocarbon-surfactant blends, terpenes, esters or glycol ethers. The second type, *water miscible compounds*, includes alcohols, ketones and amines. Semi-aqueous cleaners combine the advantages and disadvantages of both aqueous and solvent processes as outlined below.

These chemistries have a full range of capabilities. They may be used in an immersion system (i.e. dip tank) to remove mounting wax or may replace a non-aqueous solvent like methyl ethyl ketone in a hand wiping operation. Semi-aqueous systems are used extensively in the metal working and electronics industries. Immersion systems for parts cleaning may include an alcohol or mineral spirits rinse for water sensitive products. Semi-aqueous cleaners work well in closed-loop systems.

Typically the same type of cleaning equipment may be used with semi-aqueous cleaning as with aqueous cleaning depending on the chemistry. Ventilation is necessary and recycling schemes will vary depending on the solution. The following process equipment may be used in semi-aqueous cleaning: unheated dip tanks for low flash point cleaners and heated tanks for custom blends. Spray cleaning in an inert atmosphere may also be used. Vacuum distillation systems may be used

to recover spent cleaner. For recycling low volumes, carbon adsorption/ion exchange may be used and for recycling high volumes, membrane filtration may be more economically feasible.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>Excellent cleaning of difficult soils (greases, waxes, tar).</p> <p>Little or no residue following rinsing.</p> <p>Neutral solutions will not etch metals.</p> <p>Low surface tensions compared to water allow penetration of blind holes and crevices.</p> <p>Cleaning components are not typically volatile, reducing worker exposure.</p> <p>Lower vapor pressures when emulsified with water.</p> <p>Some are biodegradable with low toxicity.</p> <p>In well-maintained systems, chemicals only need to be added as make-up for evaporation.</p> <p>Lower volumes of solution used when compared to aqueous chemistries.</p> <p>Capable of high soil loading while still maintaining cleaning ability.</p> <p>Ability to tailor the cleaning chemistry to specific soils - custom blends.</p> <p>No ozone-depleting potential.</p> <p>Low concentrations of metals in waste.</p> <p>Cleaning solution can be recycled using skimming or membrane filtration.</p> <p>Organic effluent may have fuel value.</p>	<p>Generally high initial costs.</p> <p>Chemistry can be expensive (\$1.50 to \$5 per pound).</p> <p>Not as widely demonstrated as aqueous or solvents.</p> <p>Flammability; low flash points in some cleaners may require a closed system, an inert atmosphere (e.g., nitrogen blanket), spray under immersion, or cleaning without spray or heat.</p> <p>Some have objectionable odors.</p> <p>High soil loading may make recycling of some cleaners difficult.</p> <p>Some contain significant concentrations of volatile organic compounds.</p> <p>Some may be incompatible with plastics, aluminum or magnesium.</p> <p>Accelerated drying may be necessary.</p> <p>Evaporative losses can create an imbalance in water/solvent emulsion.</p> <p>Discharge may have high BOD.</p> <p>Higher number of waste streams to manage when compared to aqueous or solvent systems alone.</p>

Semi-Aqueous Success Stories

Raytheon, after extensive evaluation, chose semi-aqueous technology for cleaning printed wiring boards. In their Andover, Massachusetts facility, Raytheon uses a terpene cleaner with a water rinse to remove flux from these electronic packages. In addition to a relatively simple immersion system, Raytheon evaluated an enclosed spray system with an inert atmosphere (nitrogen) to reduce the danger of explosion from the terpene aerosol.

An optic manufacturer is using a terpene chemistry to clean wax from heat and water-sensitive lenses. A room-temperature dip tank holds the cleaner, and an isopropyl alcohol (IPA) hand wipe is used to rinse the lenses. Although this is a labor-intensive process, it is limited to a small portion of the facility's production, and it is the most effective way to clean this difficult soil on sensitive substrates.

2.4 ALTERNATIVE SOLVENTS

2.4.1 Petroleum Distillates

Petroleum distillates are hydrocarbon solvents that were used extensively prior to the introduction of chlorinated solvents. Industries switched to chlorinated solvents due to safety concerns about the flammability of petroleum distillates. The phase-out of some chlorinated solvents has caused many industries to resume using petroleum distillates. Included in the category of petroleum distillates are: mineral spirits, Stoddard solvent, white spirits, naphtha, and kerosene.

Typical Applications

- Generally used in the metals and printing industries for cleaning and maintenance.
- Removes: heavy oil, grease, tar, and waxes.
- Can be used as the solvent in a semi-aqueous cleaning process.
- Can be wiped on or used in an immersion tank.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Inexpensive and easy to obtain. Easy to recycle. Low surface tensions make it possible to clean "hard-to-reach" areas of complex parts. The solvents can handle high soil loads before needing to be replaced or recycled. Generally considered to be low toxicity materials. Compatible with most substrate materials.	They are photochemically reactive (VOCs). Flammability. Often contain small amounts of other listed solvents, such as benzene and toluene, that are hazardous to the environment and worker health. Worker exposure if proper ventilation is not used.

2.4.2 Aliphatic Hydrocarbons

Aliphatic hydrocarbons are similar to petroleum distillates, however, they are more refined and pure. Their long chain hydrocarbons make these cleaners immiscible in water. Evidence has shown the drying time for aliphatic hydrocarbons to be related to the flash point. A lower flashpoint results in a faster drying time. Selecting an aliphatic hydrocarbon may require a compromise between the flammability and drying time of the solvent.

Typical Applications

- Generally used in critical cleaning and degreasing operations.
- Cleans water sensitive parts and hydrocarbon based soils.
- Can be wiped on or used in an immersion tank.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Not highly volatile. When not heated VOC emissions are minimized.	The slow drying time can be a problem for parts that do not drain easily.
Can be degraded by the same microorganisms that degrade petroleum-based fuel and oil.	They are VOCs.
If the solvent being used has a flashpoint over 140 °F, and the solution contains no other solvents, and it has not picked up additional hazardous components during the cleaning process, then the material can be disposed of as waste oil.	Flammability issues if process requires spraying.
	Odors, worker exposure if proper ventilation is not used.
	May be expensive.

2.4.3 Alcohols

Alcohols generally used for cleaning are methyl, ethyl, and isopropyl. Isopropyl alcohol (IPA) is the most widely used in cleaning operations. Furfuryl alcohol can be used as a paint stripper. Alcohols are often blended with other solvents to increase their cleaning effectiveness.

Typical Applications

- Capable of removing water soluble polar compounds, and ionic soils.
- Removes: rosin fluxes, fingerprints, light oils, plasticizers and inks.
- Can be used to dry parts after water based cleaning or water rinsing.
- Generally used in immersion tanks or by wiping.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>Rapid drying times.</p> <p>Absorbs water to act as an effective drying agent.</p>	<p>Incompatible with many polymers and elastomers.</p> <p>Might not be effective in removing nonpolar soils such as waxes and oils.</p> <p>They are flammable and may be volatile organic compounds (VOCs).</p>

2.4.4 N-methyl-2-pyrrolidone (NMP)

NMP is a slightly alkaline colorless liquid with a mild odor. An organic solvent that has been available since the mid 1960s, NMP has only begun to be used extensively due to the phase-out of chlorinated solvents. NMP is miscible in water, alcohols, ethers, ketones, aromatics, and chlorinated hydrocarbons.

Typical Applications

- Generally used in its pure form, however NMP can be mixed with surfactant, thickeners, and other solvents for special applications.
- Can be mixed with water or used in conjunction with a water rinse for semi-aqueous processes.
- Can be wiped on or used in an immersion tank.
- In a parts cleaning application, NMP cleans heavy oils and carbon deposits. At 63-68°C many oils become miscible, making oil separation possible by cooling the solution and skimming off the oil.
- For paint stripping, NMP is used as a replacement for methylene chloride based strippers; NMP is slower acting but less volatile. Can be used in paint application and cleanup.
- NMP is effective at removing flux in electronics applications, however it must be used with care because it is aggressive towards plastic. Particularly suited as a conformal coating remover for the rework of coated boards.
- For use in adhesives and coatings applications, NMP is excellent on removing a wide variety of urethanes, epoxies, etc.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>Not regulated under RCRA or CERCLA</p> <p>Not listed as a Hazardous Air Pollutant (HAP).</p> <p>Low vapor pressure limits emissions to the air.</p> <p>Methylene chloride paint strippers use 4 to 6 times more product than NMP paint strippers.</p>	<p>Reproductive toxin, suspected mutagen.</p> <p>Is a volatile organic compound (VOC).</p> <p>Combustible (semi-aqueous chemistry may not be combustible depending on the NMP/water ratio in the formula).</p> <p>Dissolves plastics: polystyrene, acrylonitrile, butadiene, styrene (ABS), polyvinyl chloride (PVC), and polyesters. Parts containing these materials should be tested before switching to NMP.</p> <p>Listed under SARA Title III Section 313 and must be reported in the Toxic Release Inventory.</p> <p>Takes three times as long to strip paint as methylene chloride.</p> <p>Less effective at stripping cured, high performance paints.</p> <p>May cost five times as much as methylene chloride-based paint strippers (at \$30/gal.), and is still more expensive when calculating the volume/area savings.</p> <p>Picks up water and oxygen from the air and must be protected during prolonged storage.</p> <p>Difficult to rinse.</p>

2.4.5 Dibasic Esters (DBE)

Dibasic esters (DBE) are typically composed of 17% dimethyl adipate, 66% dimethyl glutarate, and 17% dimethyl succinate. The material is soluble in water, alcohol, ketone, ether, and most other hydrocarbons.

Typical Applications

- Paint stripping formulations.
- Often blended with NMP.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>Emissions are lower than methylene chloride because it is not highly volatile.</p> <p>Low volatility means less material used.</p> <p>Price is equivalent to methylene chloride paint strippers.</p>	<p>They are volatile organic compounds (VOCs).</p> <p>It takes 2 - 3 times longer to strip a surface with DBE than with methylene chloride.</p> <p>High cost.</p>

2.4.6 Glycol Ethers

The glycol ethers most often used for cleaning are ethylene glycol butyl ether (EB), and diethylene glycol butyl ether (DB). Newer chemistries are being developed based on propylene glycol, a less toxic alternative to ethylene glycol. Propylene based chemistries are listed on the EPA's Significant New Alternatives Policy (SNAP) list. The toxicity of ethylene glycol ethers was considered to be low, however, this is now questioned. Tests are being conducted to determine toxicity of propylene glycol ethers.

Typical Applications

- Cleaning Formulations.
- Flux, oil, grease or ink removal from glass
- Stripping photoresist materials from semiconductors.
- Components in paint strippers (replacing methylene chloride).

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Propylene chemistries clean some fluxes well.	May cause some red blood cell damage and a higher rate of miscarriages.
Propylene chemistries may provide a less toxic, less stringently regulated alternative to other alternative solvents (including ethylene glycol ethers).	Effluent foaming is possible.
Emulsify well for cleaning formulations.	Ethylene based chemistries may have odor problems
Separate well for recovering spent chemistries.	Some ethylene based glycols are considered HAPs.
	EB is EPCRA and TURA regulated.
	Glycol ethers are VOCs and flammable.

2.4.7 Ethyl Lactate

Ethyl lactate, also called lactate ester, is a clear colorless liquid with a high vapor pressure. Lactate esters are produced by the fermentation of sugar. They can be rinsed by water, alcohols, or clean lactate ester.

Typical Applications

- Removes silicone oils and greases, machining coolants, tapping oils (sulfur based), lithium grease, layout inks, and fingerprints.
- Warm ethyl lactate removes salts and flux from circuit boards.
- Currently being tested as a possible substitute for glycol ethers in the semiconductor industry.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Rinsing is not necessary, but if desired the parts can be rinsed with water or alcohol.	May be a VOC, depending on geographic location. (It is a VOC in Massachusetts). Flammable. A toxicity threshold limit value (TLV) has not been established. Cost.

2.4.8 Acetone

Acetone is a colorless volatile liquid with a mildly sweet odor. As a solvent it is classified as a ketone and is capable of removing greases, inks, oils, and waxes.

Typical Applications

- Used mainly in hand wiping applications.
- Drying agent for wet parts.
- Commonly used to remove uncured fiberglass resins, varnish, and lacquer.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Delisted as VOC by EPA and Massachusetts. Fast drying. Inexpensive.	Highly flammable. Incompatible with many elastomers and polymers. Highly volatile.

2.4.9 Volatile Methyl Siloxanes (VMS)

Volatile Methyl Siloxanes (VMS) are high purity (99.9% minimum) solvents that can be used in many situations where CFCs were used in the past. As a solvent VMS works best on nonpolar soils such as mineral and silicone oils.

Typical Applications

- Metal vapor degreasing.
- Defluxing.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Low surface tension and viscosity which permits rapid wetting of parts. High evaporation rate allows parts to dry quickly. Compatible with most materials. Exempt from federal VOC regulations. Not an ozone depletor. Relatively low toxicity.	Expensive. Flammable.

2.4.10 Hydrofluorocarbons (HFC)

HFCs are one of the few alternative solvents that can be used as a drop-in replacement for CFC-113 in vapor degreasers. They have a short atmospheric life-time and are not considered ozone depletors.

Typical Applications

- Used in vapor degreasers in situations where parts can not be cleaned by other methods.
- Generally used as a replacement for CFCs in precision cleaning operations.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
No ozone depletion potential. A long term option for vapor degreasers; there is no phaseout date. Low toxicity. Not a VOC.	Expensive. Some soils will require HFC azeotropes to be removed. They are greenhouse gases.

2.4.11 Hydrochlorofluorocarbons

Hydrochlorofluorocarbons (HCFCs) were created to be drop-in replacements for CFCs. Although HCFCs fell short of being perfect substitutes for CFCs, the solvents do have many similar qualities¹. HCFCs are technologically capable of replacing CFCs in many situations.

¹ For more information on HCFCs, refer to the Toxics Use Reduction Institute Surface Cleaning Fact Sheet #2, *HCFCs & Cleaning*.

Typical Applications

- Precision cleaning and electronics cleaning operations where other less expensive solvents do not adequately clean the parts.
- Good for degreasing, defluxing, and dewatering.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Physical and chemical properties are similar to CFC-113. Rapidly evaporates. Not a VOC. Low surface tension.	Some ozone depleting potential (ODP=0.02, CFC11=1.0) Some global warming potential. May be harmful to soft plastics. A transitional product that will be banned starting at 2010. Expensive.

2.4.12 Hydrofluoroethers

Hydrofluoroethers (HFEs) were developed by a three company consortium as a long-term replacement for CFCs. HFEs have many properties that are similar to CFCs and are capable of safely cleaning almost any material if used in an azeotropic or co-solvent process. HFEs have lower global warming potentials than CFCs and many other fluorinated compounds.

Typical Applications

- Precision cleaning and electronics cleaning operations where other less expensive solvents do not adequately clean the parts.
- Good for degreasing, defluxing, and dewatering.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Not an ozone depleting substance Not a VOC. Non-Flammable. Rapidly evaporates. Relatively low toxicity. Low surface tension makes it better than CFC's for complex parts.	Expensive. Alone it will only clean light contaminants. Must be blended with other solvents to clean moderate to heavy contaminants.

2.5 MECHANICAL CLEANING

2.5.1 Abrasive Cleaning

Abrasive cleaning processes are not new. Sand blasting, for example, has been used for years to strip paint and rust from large objects, such as buildings and ships. However, over the past several years, new abrasive technologies have emerged that are capable of removing most soils from most substrates.

Abrasive cleaning uses a media which is propelled by compressed gases or liquids to impinge on a surface. There are several factors which should be taken into account when determining the viability of abrasive cleaning:

- Type of soil or coating being removed
- Substrate material, size and thickness
- Soil/coating removal rate
- Media and waste disposal requirements

There are several advantages and disadvantages that generally apply to all of the different types of abrasive cleaning.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Eliminate or reduce the need for solvent disposal.	Not typically effective for removing fluid residues or fingerprints and usually limited to line-of-sight cleaning.
Worker exposure to hazardous solvents is low.	Usually a large capital cost involved.
Generally effective at removing scale, paint, rust and dirt on large surfaces.	May damage thin or sensitive substrates.

There are two general types of abrasive blasting systems. The direct pressure abrasive system has a pressurized hopper which contains the blasting media. The media is mixed with air at the bottom of the hopper and then propelled through a nozzle aimed at the surface to be cleaned. The high impact pressure requires operator attention to prevent over-blasting. The suction induction system mixes the air with the media in the blasting gun, not the hopper. This allows the operator to determine the appropriate abrasive/air ratio for the desired level of cleaning.

The following describes, in detail, the different types of abrasive cleaning procedures. (Success stories were adapted from the EPA software Solvent Alternatives Guide (SAGE) version 2.1.)

2.5.2 Air Blasting

Filtered and compressed air is used to remove dust and particles from parts. Ionized air can be used to prevent surface charge accumulation on nonmetallic surfaces.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
No excess waste created.	Not powerful enough to remove most soils and coatings.
Inexpensive, especially if ionized air is not needed.	

Equipment

- Blasting machine
- Particle collection system
- Source of air

Air Blasting Success Story

The employees of an oil recycling facility once used solvents to clean oil sludge from the system filters. They now use compressed air to do the same task, saving time and money.

2.5.3 Water Blasting

High pressure pumps supply water (or an aqueous chemistry) to a rotating nozzle system. The nozzles spray the water onto and impact the coated surface. The force of this impact removes the soil or paint. The water is then filtered to remove the soil and is reused.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
The stripping rates are fast.	Filtered debris may be a hazardous waste.
Does not damage most plastic or metal substrates.	Automation is often required due to the potential hazards of pressurized water.
Costs of the water and the medium pressure system are relatively low.	Equipment for generating high pressure water can be very expensive.
	Parts often have to be dried quickly to prevent rusting.

Equipment

- Blasting machine
- Debris filtration/water recycling system
- Source of water

Water Blasting Success Story

Medium pressure water is used by the automotive industry to clean floors and rails. Portable water-spray units have removal rates of 15-30 ft²/min. No abrasive is used with the water and the stripping water is collected and treated.

2.5.4 Supersonic Ice Blasting

Tiny ice particles moving at a high rate of speed remove paint, grease and dirt. Supersonic ice blasting is still in the experimental stage but it shows great promise and it should be able to be used in commercial applications soon.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
There is no wastewater to dispose of, since the ice	Removes light oils and grease, not paint or rust.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>evaporates on impact.</p> <p>Sensitive substrates will not be damaged.</p> <p>Disposal costs are low.</p>	<p>Capital costs will be high until the technology is refined.</p> <p>Noise.</p>

Equipment

- Blasting machine with a water atomizing nozzle
- Liquid nitrogen
- Debris collection system

Supersonic Ice Blasting Success Story

Ice blasting has started to be used experimentally within the United States to clean metals, rubber, concrete, and plastic surfaces in the nuclear industry.

2.5.5 BOSS - Bicarbonate of Soda (Baking Soda) Stripping

The sodium bicarbonate is propelled by compressed air to a nozzle where it mixes with a stream of water. The sodium bicarbonate/water mixture is accelerated and impacts the coating. Sodium bicarbonate crystals break down on contact with the substrate and water helps control the dust generated when the media impacts the soil.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
<p>Media is non-toxic, non-flammable, non-sparking and water-soluble.</p> <p>Equipment optimizes the use of the baking soda, which is inexpensive.</p> <p>The blasting process can remove top layers of paint without harming the primer coat.</p> <p>Generates 1/7 the waste volume of sand blasting.</p>	<p>The baking soda media is not recyclable.</p> <p>Sewer disposal requires large volumes of wastewater for pH neutralization purposes.</p> <p>An exhaust ventilation system should be used to aid in the removal of airborne particulates.</p>

Equipment

The equipment used in this media blasting technology is a blasting machine, a debris collection system, a dust suppression system, a water source and an air source.

Baking Soda Blasting Success Story

A German Navy frigate had several top coats of paint removed using baking soda stripping. The stripping was finished a day ahead of schedule and the equipment and media expenses were less than \$100,000, one-fifth of the sandblasting estimates.

2.5.6 Sand Blasting

Fast-moving grains of sand remove rust, scale, and paint from solid surfaces. It is often used to prepare surfaces for repainting.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Sand and blasting equipment are available from many vendors Inexpensive	Reuse of sand is technically possible but is seldom done due to difficulties in separating the sand from the debris. Disposal costs will be high due to the large quantity of waste produced. Sand will damage most substrates over time.

Equipment

- Blasting machine
- Debris collection system
- Dust suppression system

Sand Blasting Success Story

Sand blasting has replaced a hot acid bath to descale wire-rod coils. The sand blasting requires less energy than the hot acid bath, is more reliable, and is safer for the employees to use.

2.5.7 Steel Shot Blasting

Tiny steel balls are shot out of a blasting gun to remove paint and scale from hard surfaces.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Steel shot can be magnetically separated from the debris and reused	Steel shot may damage some substrates. Recycling the steel shot can lower costs but it is more expensive than sand.

Equipment

- Blasting machine
- Debris collection system
- Shot recycling system

Steel Shot Blasting Success Story

A government research center periodically repaints a number of structures. They are currently using steel shot blasting to remove the old paint. Removal rates are about 150 sq. ft./hr. and the waste produced is about 1.5 gal./200 sq. ft.

2.5.8 Plastic Media Blasting (PMB)

Low-pressure air or a centrifugal wheel is used to project plastic media at a surface to remove coatings.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Plastics with various hardness can be used.	The plastic media is flammable.
Some plastic media can be reused up to 30 times.	The blasting equipment has a high capital cost.
Stripping process is faster than other blasting techniques.	Soft metals may be damaged.

Equipment

- Blasting machine
- Debris collection system
- Dust suppression system
- Plastic media recycling system

Plastic Media Blast Success Story

A producer of agricultural implements converted from a hot NaOH paint stripping bath to a PMB process, saving \$32,000 annually.

2.5.9 Liquid Nitrogen Cryogenic Plastic Media Blasting

Items to be stripped are sprayed with liquid nitrogen within a stainless steel cryogenic chamber. The liquid nitrogen freezes the coating, making it brittle. Plastic media are then blasted by centrifugal wheels to knock the coating off of the part.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Short cycle-time.	Thin coatings or epoxies are not removed effectively.
Low volume of waste produced.	There are part size and weight limit restrictions.
Thick coatings can be removed well.	The initial capital costs are high.
The high throughput of the cryogenic system lowers operating and labor costs.	Personal protection equipment is needed for operators.

Equipment

- Blasting machine
- Debris collection system
- Dust suppression system
- Plastic media recycling system

Cryogenic PMB Success Story

One appliance maker uses a cryogenic PMB coating removal system to strip its inventory of 13,000 coating hangers and racks. The cycle time is 10 minutes and stripping costs average 54 cents per hanger.

2.5.10 CO₂ Dry Ice Pellets

CO₂ pellets are shot through a nozzle at high velocities and onto the surface of a part to be cleaned. The contaminant is dislodged and swept away from the part by the CO₂ pellet exhaust stream. The dry ice sublimates (changes from a solid state to a vapor state without a liquid phase) leaving only the contaminant as waste.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
A wide range of pellet sizes are available to remove both soft and hard coatings.	Thin substrates may be damaged by the pellets and elastic contaminants may not be removed.
The pellets are produced from liquid CO ₂ industrial by-products so no new CO ₂ is added to the atmosphere.	Stripping process is slow.
No media disposal costs makes this process competitive with other abrasive procedures.	

Equipment

- CO₂ delivery system
- Debris collection system
- Nozzle
- Gun assembly

CO₂ Pellets Success Story

More than 50 CO₂ pellet systems have been custom configured for cleaning applications for the automotive, military aircraft and food processing industries.

2.5.11 Carbon Dioxide Snow

CO₂ is drawn from a gas cylinder and expanded through a nozzle to produce dry ice snowflakes which remove very small particles and fingerprints.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Appropriate for delicate surfaces and higher cleaning levels, including small blind holes.	The process is not designed for heavy soil loadings.
No media disposal costs make it less expensive than solvent cleaning and the capital costs are not as high as the carbon dioxide pellet system.	The CO ₂ gas must be purified so as not to introduce contaminants into the system.
The process can be optimized for different cleaning needs.	Potential for recontamination of the substrate once the CO ₂ sublimates (changes directly from a solid state to a gas without entering the liquid state).

Equipment

- CO₂ delivery system
- Debris collection system
- Blasting machine

CO₂ Snow Success Story

An avionics plant replaced Freon with CO₂ snow in the cooling of components to test them for stress defects. The company recovered their initial investment in 30 weeks and their testing process has improved.

2.5.12 Wheat Starch Blasting

Wheat starch particles are propelled by low pressure air to gently remove most organic coatings.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Different sizes of wheat allow removal of a variety of coatings and it is biodegradable.	Harder coatings tend to break down the wheat media.
Relatively inexpensive.	Dust created by the impacts can be hazardous and flammable.
The biodegradation process, which separates the wheat from the debris and then breaks the wheat down into CO ₂ and water, saves on disposal costs.	Generally slow to moderate stripping rates.

Equipment

- Dust suppression system
- Debris collection system
- Blasting machine
- Wheat biodegradation process system

Wheat Starch Blasting Success Story

A military aircraft maintenance facility is using wheat starch media blasting to remove different coatings from aluminum and fiberglass substrates. The facility has found that selective stripping is possible using this media.

2.5.13 Food By-Products

Ground walnut shells and corn cob can be used in a blasting process to remove deposits.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Does not damage most substrates.	Paint, rust, and scale are not easily removed.
No toxicity concerns.	No media recycling.
Relatively inexpensive.	Large volume of waste for disposal.

Equipment

- Blasting machine
- Debris collection system
- Dust suppression system

Food By-Products Blasting Success Story

Brass and stainless steel stamped parts are polished and dried using a vibratory finisher containing heated cob meal media. This process costs less and is much safer to use than the previous CFC process.

2.5.14 Vacuum Blasting

Media is accelerated to the substrate using a vacuum system, rather than compressed air. This system can also incorporate multiple, reciprocating needles or brushes instead of blasting media to pummel dirt and scale from surfaces.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Recyclable media can be used with this system so no excess waste is created.	This system is labor intensive which tends to result in low stripping rates
Worker exposure to potentially hazardous materials is minimized since the media and the soil are pulled back to a holding bin.	Vacuum systems are generally more expensive than compressed air systems.
The needle or brush system saves on media costs.	

Equipment

- Blasting machine
- Debris collection system
- Dust suppression system

Vacuum Blasting Success Story

An electronics plant used acids to clean copper generating 40,000 lb/yr of hazardous waste. The plant switched to a rotating brush system which scrubbed the copper. No more hazardous waste was produced and the initial equipment costs were recovered in three years.

Table 2.1 provides cost data for the blasting techniques described in this section.

Table 2.1: Economic Analysis of Blasting Techniques (Based on 100,000 Sq. Ft. Processed)¹

Note: all figures are estimated averages.

	Sand without Recycling	Sand with Recycling	Plastic Media	Steel Shot	Sodium Bicarbonate	Carbon Dioxide Pellets
Capital Costs	\$15,000	\$30,000	\$40,000	\$50,000	\$20,000	\$45,000
Time Needed to Strip	600 hours	600 hours	1,200 hours	440 hours	1,750 hours	1,160 hours
Material Usage	150 tons/yr.	30 tons/yr.	5.4 tons/yr.	2 tons/yr.	52.5 tons/yr. of sodium bicarbonate 210,000 gal. water/yr.	510.4 tons/yr. at flow rate of 400 kg./hr.
Operating Costs w/o labor considerations per year	\$6,500	\$3,500	\$6,700	\$1,800	\$22,000	\$70,000
Nonhazardous Waste Disposal Costs per year	\$7,500	\$1,500	\$270	\$200	\$200	\$200
Hazardous Waste Disposal Costs per year	\$230,000	\$44,500	\$8,300	\$3,200	\$128,000	\$200
Total Cost (excluding labor) for Year 1 (if nonhazardous)	\$29,000	\$35,000	\$46,970	\$52,000	\$42,200	\$115,200
Total Cost (excluding labor) for Year 1 (if hazardous)	\$251,500	\$78,000	\$55,000	\$55,000	\$170,000	\$115,200
Total Cost (excluding labor) for First 5 Years (if nonhazardous)	\$85,000	\$55,000	\$74,850	\$60,000	\$131,000	\$396,000
Total Cost (excluding labor) for First 5 Years (if hazardous)	\$1,197,500	\$270,000	\$115,000	\$75,000	\$770,000	\$396,000

¹Crumpler, Paul, "Waste Not, Want Not," Pollution Prevention Technical Bulletin, Water Environment Federation Supplement to Industrial Wastewater, pp. 4-8.

2.6 EMERGING AND HIGHLY SPECIALIZED TECHNOLOGIES

2.6.1 Supercritical CO₂

Supercritical fluids are materials that when heated and pressurized above a certain temperature and pressure, into the fluid's "critical range," (for CO₂, when temperature is approximately 31°C and pressure is approximately 1070 pounds per square inch)¹ have properties between those of a gas and a liquid. In this state, the fluid can dissolve chemical compounds like a liquid, as well as penetrate small crevices like a gas². These properties make supercritical CO₂ effective in cleaning operations. In supercritical fluid cleaning the contaminated part is placed into an extraction vessel to which the supercritical fluid is continuously added. The contaminant is dissolved in the supercritical fluid. The fluid is then expanded by passing it through a pressure reduction valve or the temperature is lowered using a blower. This lowers the solubility of the contaminant in the supercritical fluid and allows separation. The supercritical fluid is recycled and the pure, extracted contaminant can also be recycled depending on the application.

Typical Applications

- Precision cleaning of metals, certain plastics
- Cleaning of printed wiring boards and electronics
- Cleaning of porous ceramics
- Removal of silicone oils, flux residues, petroleum oils, machining oils, dielectric oils, lubricants, adhesive residues, plasticizers, fats and waxes.³

¹ <http://pprc.pnl.gov/pprc/p2tech/cp2/co2intro.html>; "Supercritical Carbon Dioxide Cleaning Technology Review".

² <http://www.ilsr.org/carbo/ps/factsh12.html>; "Supercritical Carbon Dioxide: Uses as an Industrial Solvent".

³ http://clean.rti.org/sc_gen.htm; "Supercritical Fluids".

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Recyclable and non-toxic.	Use of high pressure components is a safety concern.
Cleans as well as CFC-based systems.	Potential for asphyxiation if CO ₂ leaks.
Can use recovered CO ₂ from industrial processes.	Incompatible with certain plastics.
Shorter cleaning time required than for aqueous and solvent cleaners.	High capital cost.
Is a non-VOC chemical.	Poor removal of hydrophilic (“water loving”) contaminants.
Works well with intricate parts.	Does not remove loose scale.
Supercritical fluids are capable of penetrating small crevices on parts.	Part size is limited by the size of the extraction vessel.
Additional drying and rinsing are not required.	

Equipment

- Heat Exchanger - to raise and lower temperature
- Extraction Vessel - where supercritical CO₂ is combined with contaminated part
- Pressure Control - compresses and expands CO₂
- Separation Vessel - where contaminant and CO₂ are separated

Supercritical Carbon Dioxide Success Story

The United States Air Force Materiel Command at Newark Air Force Base is using supercritical carbon dioxide as one of several alternative cleaning methods. Previously, 2,000,000 pounds of CFC-113 and small quantities of methyl chloroform, CFC-12 and trichloroethylene were being used annually for precision cleaning of various metals, plastics and epoxies. A 90% reduction in ozone-depleting solvents was anticipated upon completion of this project.

2.6.2 Ultraviolet/ozone

Ultraviolet (UV) cleaning removes trace amounts of organic contaminants in a dry process. This process, which occurs in an oven, begins with a UV lamp which emits UV energy. The energy is emitted in two wavelengths. The energy from one of the wavelengths is absorbed by the oxygen and produces ozone while the energy from the other wavelength is absorbed by organic materials and increases their molecular activity so they will react with ozone. This results in the organic contaminants being oxidized and broken down.

Typical Applications

- Substrate cleaning prior to thin film deposition
- Cleaning and sterile storage of metal tools and parts
- Cleaning of surfaces prior to hermetic (ultra-high vacuum) sealing
- Cleaning of silicon wafers, lenses, mirrors, and solar panels

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Cleaning time is short, usually 5-10 minutes.	If not maintained properly, the UV, ozone or mercury from the lamps can be a health hazard.
Works well on small amounts of organics.	Does not work on particulates or salts.
Commercial equipment is relatively inexpensive.	Dependence on line of site makes it unsuitable for many intricate parts.
Works best for removing thin organic films and for achieving high cleanliness levels.	
Works well on many glass and metal surfaces.	
Easy to maintain and operate.	

Equipment

- UV lamp - to provide UV light and produce ozone (ozone may also be supplied from an outside source)
- Oven chamber - where UV light and ozone are combined with contaminated parts

2.6.3 Laser Cleaning

Laser cleaning uses short pulses of high peak power laser radiation to physically remove or rapidly heat and vaporize a thin layer of contaminants. The vapors are removed by entrainment into a flowing gas stream and are filtered out with a HEPA (High Efficiency Particulate Air) filter.

Typical Applications

- removal of paint from large aircraft surfaces
- removal of thin films and particles from semiconductor wafer surfaces
- cleaning surgical implants
- optical fiber cleaning
- food and beverage container cleaning
- flat panel displays and printed wiring boards

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Works on partially or completely assembled parts.	The characteristics of the substrate and the contaminant must be known so that optimal absorption frequency can be chosen.
Can remove very thin layers such as chromium oxide from 304L stainless steel.	Equipment is generally expensive.
The only waste is the material vaporized from the substrate surface.	
A small area of a part can be cleaned rather than the entire part.	
Process is fast and energy efficient.	

Equipment

- Laser light source and focussing lenses
- Inert gas source
- HEPA filter - to filter contaminants from gas stream
- Blower - to move gas across surface to be cleaned
- Enclosure or surface scanning equipment

2.6.4 Xenon Flash Lamp Cleaning

Xenon flash lamp cleaning vaporizes organic coatings by using intense, pulsed light energy. A quartz tube filled with xenon gas is electrically energized 4 to 6 times per second to emit a brilliant flash of light. As this energy is absorbed by the coating, the surface temperature rises to the point at which a thin layer is vaporized and released from the surface.

Typical Applications

- removal of dark, low-gloss coatings
- removal of paint from large aircraft surfaces

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Coatings can be removed without damaging composite or metal substrates at a rate of up to 4 sq ft/min.	Expensive.
Original primer coatings and chromate conversion coatings can be left intact.	Leaves an oily layer on the stripped surface so final cleaning is required.
Little secondary waste.	

Equipment

- Xenon lamp - to vaporize contaminant
- Chamber - for cleaning to take place

2.6.5 Plasma Cleaning

In plasma cleaning, radio-frequency or microwave energy is applied to an electrically conductive gas in a sealed, low pressure reaction chamber. When voltage is applied, the gas molecules become excited and release active chemical radicals and ultraviolet waves which react with the contaminants and break them down.

Typical Applications

- electronics industry for contacts requiring high conductivity
- semiconductor wafers
- flux removal (at the molecular level)
- stainless steel syringe needles
- angioplasty balloon catheters
- plastic lenses

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
No solvents.	High initial costs.
Able to clean assemblies containing different materials.	Low cleaning capacity. Will not remove gross contamination.
Blind holes are readily cleaned.	Only removes organics and hydrocarbons.
The process may physically alter the properties of plastic surfaces which sometimes enhances the ability to form adhesive bonds.	Not typically used for final cleaning step.
Batch or continuous cleaning may be performed.	
Low temperatures and low operating costs.	

Equipment

- Vacuum system - for pressure control
- Radio frequency generator - for energy generation
- Impedance matching network
- Gas controller - for gas delivery
- Reaction chamber
- Microprocessor-based controller

2.6.6 Vacuum Degreasing

These closed-loop, low emission degreasers remove oils and greases from metal or nonmetal parts. The degreasers can be used without any liquid, with solvents (typically perchloroethylene), or with water. In *vacuum degreasing* (without liquid), the parts being cleaned are loaded into a vacuum chamber. Air is evacuated from the chamber while at the same time, heat is added to the chamber. Under these conditions, oils and greases are vaporized. The oil and grease vapors are then condensed and collected for recycling or disposal. In *solvent vacuum degreasing*, the parts being cleaned are loaded into a preheated chamber. Air is then evacuated from the chamber creating a vacuum. The solvent is heated to a boil inside a distillation tank and the parts are exposed to the solvent vapors, as in a conventional degreaser. The contaminants and the dirty solvent fall back into the distillation chamber. The solvent is boiled off in the distillation process leaving only the contaminants for disposal. The solvent vapor is then sent to a condenser where it can be recovered for reuse. In *aqueous vacuum degreasing*, the parts being cleaned are loaded into a vacuum chamber. The chamber is then filled with a heated aqueous solution. Air is injected into the solution to provide aeration and aid in the cleaning process. After the cleaning cycle, the aqueous solution, with the contaminants, is evacuated from the chamber and the parts are dried under a vacuum. The contaminants can then be skimmed or otherwise removed from the aqueous solution which can then be recycled and reused.

<i>Advantages</i>	<i>Disadvantages or Challenges</i>
Vacuum drying is fast and effective, especially if parts have blind holes.	Specifically suited to remove oils and greases, not other types of soils.
Ultrasonics can be added to some models if higher cleaning levels are needed.	The floor space required by this degreaser is greater than for typical vapor degreasers.
The solvent or aqueous solutions can be almost fully recovered and reused.	Capital costs of these systems are high, often prohibiting their use by small companies.

Equipment

- Cleaning chamber
- Vacuum drying chamber
- Refrigerated condensing unit (to collect oils for recycling or disposal)

Vacuum Degreasing Success Story

A manufacturer of electrical contacts switched from a vapor degreaser to a vacuum degreaser. Their cleaning quality improved and their payback will be less than three years. Savings resulted from decreased solvent use and hazardous waste disposal.

SECTION 3: POST CLEANING: RINSING, DRYING, QUALITY EXAMINATION

3.1 RINSING

The majority of aqueous and semi-aqueous processes are followed by a rinsing stage. Although most design efforts are focussed on the cleaning stage, the rinsing stage deserves just as much attention in order to assure an acceptable cleanliness level. Rinsing can be accomplished using water, acetone, alcohol, hydrofluoroethers, etc. This section will focus on the use of water for rinsing. Four major factors affect rinsing effectiveness: 1) water quality, 2) agitation, 3) rinse temperature, and 4) additives.

Water quality is the most important aspect of successful rinsing. A part will only be as clean as the water that is rinsing it. In cases of low to moderate cleaning specifications, ordinary tap water may be appropriate. When higher specifications must be met, deionized (DI), distilled or ultrapure water should be used. The use of these waters improves final product quality and eliminates problems (e.g., spotting, streaking, ionic contamination) caused by impurities. DI water is very high quality water with low concentrations of dissolved impurities. A typical DI system consists of a cartridge micro filter to remove large particulates, activated carbon bed to adsorb organic contaminants and anionic and cationic exchange resins to remove dissolved ionic material (e.g., metals and hard water ions). Following the deionization process, resins are regenerated using acid or caustic chemicals to displace the captured ions, which results in a concentrated waste stream. Distilled and ultrapure water are rarely used due to the large energy requirements, but may be applicable for small volume applications where the capital expenditure for a DI system is not available.

Agitation for the rinsing stage is basically the same as for the cleaning stage. Rinsing may be enhanced with spray, agitated immersion, ultrasonics, tumbling or oscillation.

Rinse temperature is a concern for many reasons. Unlike a cleaning process, higher temperature is not always more effective. High rinse water temperatures will make drying easier and will be more effective in rinsing plastics. However, increased corrosion rates and spotting may result especially when rinsing with poor quality water or in the presence of silicated chemicals.

Additives such as rinse aids and corrosion inhibitors may be used in a rinse bath to increase rinsing efficiency. Rinse aids are usually translucent surfactants added to rinse baths to increase the wetting ability of the water. This is accomplished by lowering the surface tension so that the water can penetrate small surfaces. Rinse aids also aid in the drying stage by increasing the sheeting action of water, allowing the water to easily drain from the part. Although these rinse aids are translucent, they remain on the part after drying. Testing will be necessary to ensure that this does not interfere with any further processing of the part. For some applications, a water-alcohol mixture is used for rinsing because the alcohol effectively reduces the surface tension of the water. Corrosion inhibitors, usually silicate salts, are used in a rinse stage to prevent rusting of ferrous metals. If corrosion inhibitors are used in the final rinse stage, like rinse aids, they may remain on the part and the parts should be tested to ensure that the inhibitors do not interfere with further processing.

Efficient Use of Water

The rinsing stage uses the majority of water in a cleaning system. Therefore, it is important to conserve water through rinsing techniques and recycling efforts. One way to reduce rinse water use is to minimize the dragout of cleaning solution from the cleaning stage. This can be accomplished by increasing the drip time or installing a countercurrent rinse system. Conventional dump rinsing techniques (i.e., using a rinse tank until the contaminants make rinsing ineffective and then dumping the tank) can perform excellent rinsing in a single tank, but require a large volume of water. A countercurrent rinsing system is a series of rinse tanks, usually three, connected to each other. The effluent from each rinse stage is pumped from the cleanest tank to the dirtiest and the parts move from dirtiest to cleanest. In this manner, the parts will be rinsed in increasingly clean water with the last stage being relatively pure water. The water from the first rinse (dirtiest) stage flows out through the top of the tank to remove dragout oil and cleaning solution. This water is then either disposed of or recycled. Countercurrent systems can reduce rinsewater volumes by 95%¹, but may require additional floor space and capital costs.

Recycling and Disposal of Rinsewater

Evaporation/Condensation may enable reuse of the rinsewaters. Capital investment in these systems is relatively low, however, they require a large amount of energy. Evaporation/Condensation may be most applicable for smaller volumes of water. Larger volumes of water can be recycled by using a combination of reverse osmosis, membrane filtration, carbon adsorption and cationic/anionic ion exchange. Depending on the cleaning solution and contaminants, the spent rinse water may be used as a pre-wash, sewerage or disposed of as an industrial wastewater. The proper regulatory agency or technical assistance office should be contacted to determine the appropriate disposal method.

¹Hazardous Waste Reduction Program of Oregon, "Guidelines for Waste Reduction and Recycling," July 1989.

3.2 DRYING PARTS WHEN USING AQUEOUS OR SEMI-AQUEOUS CLEANING SYSTEMS¹

When part cleaning is accomplished using chlorinated solvents, fast and high-quality part drying is attained by the evaporation of the solvent. This makes part drying simple. However, due to phase-outs of the most ozone-depleting chlorinated solvents (CFCs and trichloroethane) and concern over the carcinogenicity of some others (trichloroethylene, methylene chloride and perchloroethylene) users are switching to aqueous cleaning technology. Drying water from parts is not a simple task, especially from intricate sections. When asked about their satisfaction with aqueous cleaning systems, some users complain that the quality of the drying is poor, slow, or that mineral deposits are left on the part surface. This section describes the part-drying methods, provides costs associated with the methods for comparison and suggests solutions to some of the drying problems experienced when switching to aqueous cleaning systems.

3.2.1 Importance of Drying

Drying is not usually a step that can be ignored. For steel and aluminum parts, for example, effective drying reduces rusting and corrosion of parts. Where cosmetics are important, drying can minimize spotting. In addition, drying may be necessary to prevent the unacceptable processing of a part in subsequent manufacturing steps (e.g., an insufficiently dried part may not accept a coating). Depending on the application, simply allowing the evaporation of the hot aqueous cleaning solution or rinsewater as the part exits the cleaning system may suffice.

3.2.2 Selecting The Proper Drying Method

Because accelerated drying capabilities are often required in an aqueous cleaning system, many vendors offer combined wash/rinse/dry systems. However, a little knowledge about drying methods will assure the purchase of the lowest-cost system that is effective for a particular application. Selecting the proper drying method depends on the following:

- nature of the parts including the substrate material and surface intricacies
- number of parts to be dried
- degree of dryness required
- subsequent operations

3.2.3 Methods of Drying

There are three major drying methods. They are used separately or in combination.

1. Mechanical (e.g., air blow-off, air knife, vibration, and centrifugal or tumbling)
2. Evaporation (e.g., hot forced air, infrared and vacuum)

¹TURI Surface Cleaning Series Fact Sheet #3 “The Drying Options.”

3. Displacement

Mechanical

In this drying process, mechanical action is used to remove water from the parts' surfaces. This is most often used for gross water removal. Depending on the part type, mechanical drying is relatively fast and has a low energy requirement. Mechanical drying will remove a large percentage of the water quickly with low energy input, but cannot typically remove trace amounts. Mechanical drying also includes manual wiping which is a common drying technique.

Air Blow-Off: high velocity compressed or blown air displaces films of water from complex surfaces. The air is typically filtered to remove oil and water. This method is effective at removing water from internal sections (e.g., holes) and is best suited for medium- to large-sized parts and low production rates. This is typically a hand-held air gun that requires manual direction of the air. The compressed air method may be noisy.

Air Knife: a high velocity air part drying system that focuses compressed or blown air to a desired location. Water droplets are physically blown off the parts. Air knives can complement any drying method. Because air knives are throttled to entrain surrounding air, they use less air and are quieter than the compressed air method. Air knives are most effective in in-line, continuous cleaning systems.

Vibration: a low-frequency vibration (10 to 100 cycles/sec) is applied to enhance the effects of gravity and increase draining.

Centrifuge: the part is placed in a cylindrical compartment (centrifugal dryer) and spun about a central axis to remove water from its surface. This method is most effective for small parts with simple geometries, however it has damaged some part geometries. Dryness-to-the touch is attained with relatively low operating cost. Some units include the use of hot forced air.

Evaporation

In this drying process, heat or pressure is used to convert water to a vapor. Evaporation is not recommended for parts with low heat tolerance (e.g., plastics). It is not effective for parts that have large surface area to volume ratios. In addition, it may leave a non-volatile residue and increase the rate of part corrosion.

Hot Forced Air (or gas drying): widely used in commercial systems for a variety of drying requirements. Large equipment spaces and operating costs are required for this method.

Infrared: infrared light bulbs create the heat required for evaporation. This method involves a low capital investment but is not energy efficient compared to the other methods.

Vacuum: the boiling point of the water is lowered by a decrease in atmospheric pressure and moisture is removed from part surfaces. This method is effective on parts that are heat sensitive, have complex geometries or high surface area-to-size ratios. Large part size may prohibit the use of this technology.

Displacement by Insoluble Materials

In this method of drying, water is displaced by another liquid. Materials commonly used for displacement are perfluorocarbons (PFCs), alcohol, ether, and glycol. This method is effective on any size part and on parts with complex geometries. A higher level of dryness is attained than with the other methods. However, environmental, safety and health issues associated with some displacement materials may detract from their drying abilities.

3.2.4 Cost of Drying

When attempting to compare different technologies, both operating and capital costs must be considered. For drying systems, operating costs include material purchases, energy, maintenance, safety training, and labor. Capital cost is the initial cost of the equipment. Capital costs for drying systems are hard to generalize because they are application-specific. The capital costs depend on the method chosen and the number and size of the parts. Since capital and operating costs increase exponentially for each per cent of water mass removed, it is advisable to avoid over-drying of parts. The level of dryness depends on the intended use for parts after the drying operation. For some operations, minimal drying is needed (e.g., for storage), dry-to-the-touch may be needed for shipping, inspection, assembly or surface finishing (e.g., painting and plating). Processing in a clean room requires a very high level of dryness.

Typically, air knives have lower operating costs than other drying methods because they consume less energy. Centrifugal dryers usually consume less energy than compressed air blow-off or hot forced air systems. The maintenance and operating costs are relatively low for centrifugal drying systems. When considering the operating costs associated with displacement materials, do not neglect the costs of regulatory compliance (e.g., environmental and safety regulations).

3.2.5 Drying Problems and Possible Solutions

Table 3.1 presents common drying-related cleaning problems and possible solutions.

Table 3.1: Drying-Related Cleaning Problems and Possible Solutions

Drying-Related Cleaning Problem	Possible Solutions
Residue on part surface	<p>In order to diagnose the problem, observe the contaminant, cleaner and evaporated water on the substrate's surface with a microscope using the same magnification. Then,</p> <ol style="list-style-type: none"> 1. Cleaners containing silicates bond to surfaces at elevated temperatures, especially anhydrous silicates. Reduce cleaning and rinsing bath temperatures before trying a non-silicated or liquid-based silicated cleaner. 2. Hard water may be the source of spotting. Analyze water quality of cleaning and rinsing tanks. Use a higher quality water in the final rinse. 3. Residual amounts of contaminants or cleaners may be present in rinse water. Use high velocity air blow-off instead of evaporation for drying.
Difficulty drying internal sections of parts	<ol style="list-style-type: none"> 1. Try vibration, tumbling or high velocity blow-off. 2. Use a rinse-aid in rinse stage to lower the surface tension of the rinse water. However the rinsing agent may leave a transparent surfactant film on the part that may influence quality. 3. Increase the rinse temperature 4. Before drying, make sure that parts are positioned for maximum drainage.
Drying is slow	<ol style="list-style-type: none"> 1. Increase air flow and temperature. 2. Increase rinse temperature, if possible.
Drying equipment requires additional floor space and energy	<ol style="list-style-type: none"> 1. Consolidate cleaning and other plant-wide operations. 2. Address future production rate increases when planning available floor space prior to installation. 3. Use second heater to overheat air and focus this on difficult-to-dry areas.¹ This avoids over-drying in easy-to-dry areas.
Parts are heat-sensitive	<ol style="list-style-type: none"> 1. Determine product-specific temperature tolerances with well-established performance parameters (for example, age acceleration). 2. Look at non-heat methods (vacuum drying) or a combination of methods.
	<ol style="list-style-type: none"> 1. Inquire of chemical manufacturer if cleaner is

¹Durkee, John, "Why is Drying so Hard with Aqueous Cleaning Technology?" Products Finishing, September 1995, p. 64.

Corrosion	<p>available with inhibitor additive.</p> <ol style="list-style-type: none"> 2. Increase existing inhibitor levels. 3. Decrease temperature of final rinse to ambient. 4. Do not use hot air in the drying stage. <p>* Although heating reduces drying time, it greatly increases the likelihood of corrosion since corrosion is exponentially related to temperature.</p>
Water does not drain easily	<ol style="list-style-type: none"> 1. Use a rinse aid. 2. Apply vibration and/or tumbling drying methods. 3. Blow-off as much water as possible.
VOC content of displacement methods	<ol style="list-style-type: none"> 1. Minimize solvent dragout loss. 2. Add scrubbers to collect vapors (not a TUR technique). <p>Remember to check the local regulatory status of drying solvent as regulations vary depending on location.</p>

3.3 EVALUATION OF PART CLEANLINESS

Evaluation or verification of part cleanliness is a necessary part of evaluating alternatives to a current cleaning processes. The verification method chosen depends on the part material, soils, and level of cleanliness required. These tests may be used only during the evaluation phase of alternative selection, or they may become part of the production process. The more common tests for cleanliness verification are described here in two categories: visual methods and quantitative methods of surface analysis.

3.3.1 Visual, Qualitative and Practical Methods

Quite often, the best test of a cleaning process is *Functionality*. In this test, parts are cleaned with a new process and processed as usual. The outcome of the subsequent processing is then examined for acceptability (e.g., quality of plated finish or weld). Standard test methods exist for some of the subsequent processing (e.g., adhesion STM-30-104/105 and age acceleration).

The *Water Break Test* assesses the ability of water to “wet” surface. Water will wet (i.e., spread out on) a clean non-oily surface, such as metal or ceramic, whereas an oil film on the surface will cause the water to “break” or bead up. This test is performed simply by immersing a part in a beaker of water at a specified angle and speed and visually inspecting how the water sheets off of the part. It is simple and inexpensive, but is limited to parts with smooth surfaces.

The *White Glove Test*, *Wipe Test* or *Tape Lift Test* can be used to check for residual contaminants. These tests are also simple and inexpensive but are limited to contaminants that can be seen on clean white gloves, wipes, swabs or tape.

Many organic films, oils and particulates are fluorescent which allows their visual examination using *black light*. This technique is simple and inexpensive. Fluorescent “tags” can be purchased and added to contaminants which do not fluoresce.

Optical Light Microscopy using a high power microscope or a stereo-zoom microscope allows visual examination of the part surface before and after contamination and after cleaning tests. With this method, the difference between residual contaminants and detergent can be discerned. Although useful for laboratory testing, it is not widely used in production.

Measurement of *Surface Energy* uses a graded set of solutions of known surface tension to establish the surface energy of the cleaned part, by noting whether a drop of solution wets or beads up.

3.3.2 Quantitative Methods

Gravimetric Analysis uses an analytical balance to establish weights of parts that are pre-cleaned, contaminated and cleaned. The amount of contaminant is determined by subtracting the “preclean” weight from the “contaminated” weight. The performance of a cleaning process is determined by the amount of contaminant removed which is calculated by subtracting the “clean” weight from the “contaminated” weight. From these values, % removal of contaminant can be calculated and compared to other cleaning trials. This method also identifies etching of base material when the “clean” weight is less than the “preclean” weight. This process is useful for lab comparisons of different trials and is relatively inexpensive, but is limited to small parts.

Surface Quality Monitor/Optically Stimulated Electron Emission (OSEE) uses an ultraviolet (UV) light source to illuminate the part surface. Electrons are emitted from certain surfaces when exposed to the UV light. The resultant electrons are collected and measured as a current. Contamination on the surface acts as resistance to the current and lowers the measured signal. This method is quantitative, non-destructive and fast, but requires calibration for each soil.

Laser Contact Angle Goniometry measures the contact angle of a drop of deionized water sitting on a flat surface of a part. The contact angle is influenced by the cleanliness of the surface. Typically, the cleaner the surface the lower the contact angle for a standing drop of water.

Extraction (Indirect) Methods rely on residual contaminants being removed by solvent extraction. The solvent is then analyzed by gas chromatography/mass spectroscopy (GC/MS), Fourier Transform-Infrared (FT-IR) spectroscopy, particle counting, turbidity, conductivity or simply passing the fluid through filter paper and subsequently analyzing the filter paper by weighing, microscopy or visual inspection. For evaluating the cleanliness of electronic components, more advanced analytical methods may be used (e.g., high performance liquid chromatography, secondary ion mass spectroscopy, scanning Auger electron spectroscopy, gas permeation chromatography, x-ray photoelectron spectroscopy). These methods assume that solvent extraction will remove residuals that original cleaning method did not and may be limited by the availability of analytical equipment.

The *spectroscopy methods* allow the determination of the compositions of the contaminants and comparison of cleaning systems’ performances by comparison of peak size on subsequent spectrum.

Particle Counting Systems provide a count of the particulate matter on a part. Particles are collected by immersing the part in a pure fluid, such as DI water. The liquid then passes through a sensor that detects how much light is blocked by the particles and creates an electrical pulse that is proportional to particle size. Results are reported as total particles, particles per milliliter, particles per part, particles per unit surface area or particles per unit volume. This technique is most often used in the electronics industry for cleanliness verification of printed wiring boards, semiconductors and disk drives. Particle

counters can be used in other, less critical, applications by calibrating the system to measure larger particle sizes.

Turbidity measurements can be used in much the same way as particle counting results. The turbidity of a solution, made by immersing the clean part in a pure fluid, is measured on a turbidimeter. Turbidity is measured in Klett units which indicates the amount of light that is scattered by the sample.

Conductivity can be determined by measuring the total ionic concentration with Ionographs or Omega Meters. However, these techniques cannot differentiate ionic species. If necessary, ion chromatography can be used to measure the specific cations and anions on a surface to the part per million.

Grazing Angle/Specular Reflectance (FT-IR) Fourier Transform-Infrared spectroscopy can be used for direct surface analysis. The composition of contaminants can be determined from the spectrum and the quantity can then be compared to subsequent spectrum.

SECTION 4: USEFUL TOOLS FOR FINANCIAL ANALYSES

4.1 FINANCIAL ANALYSIS “BEYOND SIMPLE PAYBACK”

One of the most important considerations in any project is whether it is economically viable. How much will the project cost and what is the payback or potential for savings? This section is not intended to be an in-depth study of economic theory. Rather, it provides a basic overview of items to consider when conducting an economic analysis. The questions that will be answered include:

1. What are the costs associated with using the current cleaning system?
2. What are the costs of switching to a new system?
3. How does one determine the economic feasibility of the project?

In addition, this section discusses the differences between traditional financial indicators (e.g., simple payback) and more comprehensive analyses (e.g., net present value). A sample problem is included along with a list of costs and a blank worksheet for further reference.

It is important to understand that any economic analysis is going to be specific to each company. Factors such as discount rate and tax rate vary among corporations and integrally affect the end result of financial calculations. For this reason, this section provides the tools necessary to perform an individual, personalized assessment. What works for some companies will not necessarily work for others.

To begin, it is important to define some terms. Financial calculations involve many abbreviations which make these formulas appear complicated. The actual math, however, is not difficult.

4.1.1 Definitions

Capital Costs: one time costs associated with the purchase and installation of new equipment and the removal and disposal of old equipment.

Depreciation: an accounting convention that allocates the cost of a capital asset in a systematic manner over its lifetime.

Discount Rate: a rate used to translate the future cash flow into present time values, which is based on a company's cost of capital. The cost of capital incorporates the cost of borrowing money and the return required by shareholders on the investment.

Incremental Cash Flow: the difference between the costs (or savings) of a given project and the cost of the current process.

After Tax Cash Flow: incremental cash flow minus income tax.

Internal Rate of Return (IRR): the discount rate at which $NPV=0$.

Net Present Value (NPV): the difference between capital costs and present value.

Operating Cash Flow: recurring costs generated by a project.

Present Value: the value of any future investment expressed in today's dollars.

Payback: the number of years required to recover an initial capital investment.

Tax Rate: total of all income tax rates (state and federal) charged to a company.

4.1.2 What Will it Cost to Change a Cleaning System?

This question may not be easy to answer. There are many factors to consider when assessing the cost of the current cleaning process. The analysis should not be limited to comparing the costs of chemical purchases. It is easy to look at the costs of chlorinated solvents and their alternatives on a pound for pound basis. Many times the difference in price will seem extreme. Does a new chemical that costs ten times the price of the current chemistry result in a cleaning cost that is ten times greater? Rarely, if ever, is the cost difference this obvious.

When actual usage is considered, newer, more expensive chemicals may cost less than the current process. If the current cleaner uses an older vapor degreaser with few emission controls there are some points to consider. First, much of the current chemistry is probably being lost to evaporation. Many of the more expensive chemistries are designed with efficient cleaning processes in mind. This cleaning equipment is tightly sealed to limit emissions and recycling is usually integrated into the process. To be sure, it will cost more to purchase these cleaners, but losses will be lower and thus usage will be lower. Another thing to consider: If the current process relies on an older vapor degreaser with a chlorinated solvent, there is a cost for compliance with multiple regulations. If not already done, it is likely there will be significant cost to upgrade the current equipment. There will also be a cost, in the form of labor hours or consultant fees, for annual compliance reporting and permits for these solvents. The cost of disposal should also be considered. A properly designed closed-loop aqueous cleaning system should produce less waste than the current process. Less waste translates to less cost. Perhaps the insurance carrier is imposing a hefty charge because chlorinated solvents are kept on site. Finally, the annual expenditures on health and safety monitoring, equipment and training should be considered. If a switch is made to a safer chemistry these costs should be reduced. After calculating the myriad costs of using traditional chlorinated solvents they might not seem so cheap after all.

4.1.3 Potential Costs for Conversion to a New System

Table 4.1 lists some of the costs to consider when performing a financial analysis. It is divided into two parts: one-time, or capital, costs and recurring costs. This list is not comprehensive but should provide some ideas of costs that one might not normally consider when doing simple financial calculations. Some time should be spent ensuring that everything is covered when listing the costs. The more complete the cost tabulations are, the clearer and more accurate a picture will be generated about the potential benefits of conversion.

Table 4.1: Summary of One-Time and Recurring Costs

One-Time Costs	Recurring Costs
Equipment Purchase equipment sales tax installation spare parts monitoring & safety equipment	Chemical Purchases Waste Management treatment chemicals testing disposal
Old Equipment Disposal removal labor scrap value or disposal charge	Safety Training Safety Equipment Insurance
Research and Design planning engineering consultants accounting supervision	Regulatory Fees Regulatory Paperwork Annual Permit Fees Production Costs
Initial Permits	Maintenance labor materials
Building Changes addition of space addition/movement of utilities	Utilities water electricity gas steam

4.1.4 Payback and the Case for Using Net Present Value

When performing a financial analysis it is easy to look at *simple payback* as a measure of a project's attractiveness. This, however, is not necessarily the best method to analyze the costs and benefits of a given project. Simple payback is merely a measure of the number of years it will take to recover the capital costs of a project based on its proposed annual savings. If the installation of an aqueous cleaning line is being considered at a cost of \$150,000, and projected savings are \$15,000 annually, the payback of this project is 10 years (150/15). At first glance this project may be rejected due to its long payback. However, there are drawbacks to this "rough cut" measure, and economically beneficial projects may be unfairly rejected if this is the only calculation made.

Net Present Value (NPV)

Net Present Value is the preferred method of screening projects. This calculation accounts for the time value of money. That is to say, when computing NPV, one is calculating the value of a project in today's dollars. NPV provides a way to compare projects on a dollar to dollar basis, which has been proven to be the most accurate basis for this comparison. Two projects with the same payback will most likely have different NPVs. The project with the highest NPV is the one that adds the most value to a company's bottom line.

NPV calculations are sensitive to your company's *discount rate*. This is not a number to choose arbitrarily. The discount rate is a factor that accounts for the cost of borrowing capital (such as interest rates on loans), the relative risk of a proposed project, and the required return on the investment to satisfy shareholders. Each company should have a discount rate that may be obtained from their financial staff.

Any NPV that is greater than zero shows an attractive project. In fact, for NPV equal to zero, it shows that the proposal exactly meets the financial requirements incorporated in a company's discount rate. The project *will* cover the cost of capital, the risk *is* acceptable, and the return *will* satisfy shareholders. Furthermore, an NPV less than zero might still represent an attractive project. If the proposal opens new markets, lends itself to "green" marketing or otherwise provides benefits that are difficult to assess economically, the project may be worthwhile.

Internal Rate of Return (IRR)

Internal Rate of Return is a measure of the return on investment (ROI) of a project. If the IRR is greater than the discount rate for a given project, it is economically attractive. IRR can be determined using a financial calculator, a computer spreadsheet, or a trial and error process. If the "trial and error" method is chosen, the most direct way to calculate this value is to experiment with different discount rates until the NPV of a project is equal to zero. When $NPV=0$, the discount rate is also the IRR for that project. IRR is useful for providing a percentage ROI. It is not as easy to compare actual returns between projects using IRR as it is using NPV. Remember, with NPV the final figure is in dollars. Two projects with similar IRR figures may have very different NPV values.

4.1.5 Calculating NPV

As shown by the sample problem in this section, NPV is calculated as follows:

1. Add up all of the one-time costs for conversion to the new project. This includes the types of costs that may be found in Table 4.1, such as equipment purchase and installation, initial permitting costs and building and utility alterations. The sum of these costs is known as the *Total Capital Cost*.
2. Add up all of the recurring costs for the existing system and the proposed process(es). These are the costs to run the process every year, including chemical purchase, waste management,

compliance costs, maintenance costs and utilities. The sum of these costs is known as the *Annual Operating Cash Flow*.

3. Calculate the *Incremental Cash Flow*. This is the difference between the *Annual Operating Cash Flow* for the current process and the *Annual Operating Cash Flow* for the new project. If the new project costs less to run, the *Incremental Cash Flow* should be positive (+).

To consider *Depreciation*, make this calculation now: For straight-line depreciation, divide the *Total Capital Cost* by the length of the project (in years). This is the *Annual Depreciation*.

4. Calculate *Income Tax*. This is the tax rate multiplied by the *Incremental Cash Flow*. Or, if *Depreciation* is considered, the following steps are taken: Subtract *Annual Depreciation* from *Incremental Cash Flow*, and multiply the resulting number (*Taxable Income*) by the tax rate to calculate *Income Tax*.

Subtract *Income Tax* from *Incremental Cash Flow* and this is the *After Tax Cash Flow*.

5. Find the *Present Value* factor (pV). Knowing the company's discount rate and the length of the project, Table A should be consulted at the end of this section. For projects greater than one year in length, the pV factor will be a number greater than one. Multiply pV by the *After Tax Cash Flow*. The result is known as *Present Value*.

6. Subtract the *Total Capital Cost* from the *Present Value*. This calculation is the *Net Present Value (NPV)* for a given project. If the NPV is greater than zero, the project is economically attractive.

4.1.6 Depreciation

Depreciation is an important concept in economic analysis. It allows for spreading the cost of equipment over many years so that equipment purchases will not represent a large loss during the year the purchase is made. One benefit of incorporating depreciation into an analysis is that the numbers will reflect the depreciation tax shield. Projects that may have unfavorable NPV before consideration of the depreciation tax shield may actually have a positive NPV after accounting for depreciation. The sample problem uses a straight-line depreciation model. It assumes that at the end of the project, the salvage value of the equipment is zero. To calculate annual straight-line depreciation, take the initial capital investment and divide it by the number of years for the project. A \$40,000 project in a ten year time frame has a straight-line annual depreciation of \$4,000 ($40,000/10$).

To understand the depreciation tax shield, one first must understand that annual depreciation is a non-cash expense that reduces taxable income. If the above \$40,000 project generates a savings of \$10,000 annually, these savings are taxed. If the annual income tax rate is 40%, a company would owe \$4,000 annually ($10,000 \times 0.4$) if they do not account for depreciation. However,

when the depreciation expense is included, annual taxable income becomes \$6,000 (\$10,000 savings - \$4,000 depreciation). Now the annual income tax for the company is \$2,400 (\$6,000 \times 0.4). This tax savings of \$1,600 annually represents the depreciation tax shield and increases the company's bottom line. Incorporating depreciation into your NPV calculations could alter the results significantly.

Formulas	
Present Value:	After Tax Cash Flow * pV Factor (see Table 4.7)
NPV:	Present Value - Total Capital Cost
Annual Straight-Line Depreciation:	Total Capital Cost / Project Length
Simple Payback:	Total Capital Cost / After Tax cash flow

4.1.7 Sample Problem

The easiest way to show how these calculations are performed is to look at a sample case. XYZ company is a metal fabrication firm that is studying various proposals to replace their current solvent cleaning line. They will examine three alternatives: an unregulated, non-hazardous alternative solvent, aqueous cleaning, and laser ablation. They will be looking at a ten-year project with capital costs depreciated straight line (this is to say that the initial capital cost is expensed in equal amounts every year for the life of the project) with zero salvage value. XYZ pays a tax rate of 38% on income and will examine two discount rates, 12% and 15%. Labor rates for XYZ are \$17.50 per hour and in-house staff in charge of regulatory compliance are paid \$22.00 per hour.

XYZ's current cleaning line employs two operators full time. They use the solvent methylene chloride in a vapor degreaser and the parts are dry when they leave the system. Annual methylene chloride usage trips the Massachusetts Toxics Use Reduction Act threshold of 10,000 pounds. They are required to file for an air permit and pay a \$7000 annual fee due to volatile organic compound emissions from the methylene chloride. Both operators are required to attend a \$700 safety course every two years and annual expenditures on safety equipment is \$1,000. XYZ spends \$75,000 on methylene chloride and \$2,000 on sludge disposal every year. Management decided to switch to an alternative system for a number of reasons: they wanted to reduce their regulatory burden, they hoped to modernize the cleaning line, and they wanted to decrease worker exposure to methylene chloride which is a Hazardous Air Pollutant and a suspect carcinogen.

Any new equipment may necessitate changes to the current building. XYZ has completely occupied their current facility and if the replacement system is larger than their current system, the building will require an addition.

The alternative solvent system consists of a new vapor degreaser operating with an un-regulated, non-hazardous solvent. The dual sump degreaser with distillation costs \$179,000 installed, the total capital outlay for this option.

Annual operating costs for the alternative solvent cleaning line are lower than for the methylene chloride system. Although the chemistry is more expensive than the current solvent, the new equipment is much more efficient and is designed to minimize evaporative losses. Additionally, minimal waste is generated and will cost only \$600 per year for disposal. Insurance costs represent a \$10,000 savings each year compared to traditional solvent cleaning because the new chemistry is non-hazardous. Also, safety equipment is cheaper, costing \$500 every year, and the system relieves XYZ of the burden of environmental reporting. Production will still require two operators, and process time is the same for the new system. Utilities are more expensive, with additional electrical service for the pumps and recycling system.

Alternative number two is aqueous cleaning. This process will require a retrofit to the current vapor degreaser, and requires a heated drying oven. The drying oven plus retrofits will cost \$15,000 and the building will need a \$25,000 addition to accommodate the new equipment.

Water based chemistry costs are approximately the same as solvent based. Disposal of non-hazardous waste is cheaper, and insurance and safety equipment costs are reduced. Production costs remain the same, with additional utility costs to run the drying oven.

The final option, laser ablation, requires completely new equipment. \$225,000 for the system includes all of the necessary technology, including the laser, the inert gas system with filters, and the cleaning cabinet. Extensive electrical work will cost \$4,000 to meet the demands of this process.

Laser ablation requires no chemistry, but there is a cost to purchase the inert gas (nitrogen) for this system, \$3,667 annually. This system relies on the laser to heat and vaporize the soil while the inert gas stream removes the contaminant. Production time will increase one-third due to the time required to scan the laser across the surface during the cleaning process. Also, the insurance company will not provide a discount for this relatively new system because they are unfamiliar with the technology. Utility costs increase to \$4,000 annually due to the electrical demands of the laser.

Table 4.2 summarizes the capital costs of each option that XYZ examined. Note that the capital cost of maintaining the current system is zero. If some retrofitting is required to update current equipment or to bring it into compliance, this would be recorded under capital costs and would be a factor in the calculations.

Table 4.2: Capital Costs

		Current Process	Option 1	Option 2	Option 3
	<i>Project Name</i>	METH Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
<i>Capital Costs</i>	Equipment Purchase	0	-179000	-15000	-225000
	Installation	0			
	Old Process Disposal	0			
	Old Process Scrap value	0			
	Research & Design	0			
	Initial Permits	0			
	Building Changes	0		-25000	
	Utility Changes	0			-4000
	<i>Total Capital Costs</i>	\$0	(\$179,000)	(\$40,000)	(\$229,000)

Table 4.3 shows all of the recurring costs. There is an annual cost to run the methylene chloride cleaning system, and the numbers reflect the data that were given in the introduction to this sample problem. Additionally, the costs for the alternative cleaning systems are shown here. In this example, these costs and savings do not reflect inflation and are assumed to be the same throughout the life of the project.

Table 4.3 Recurring Costs

<i>Operating Cash Flows</i>		METH Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
	Chemical Purchases	-75000	-40000	-75000	-3667
Waste Management	Treatment Chemicals				
	Testing				
Maintenance	Disposal	-2000	-600	-600	-600
	Safety Training	-700			
	Safety Equipment	-1000	-500	-500	-500
	Insurance	-15000	-5000	-5000	-15000
	Regulatory Fees	-1100			
	Regulatory Paperwork	-2640			
	Annual Permit Fees	-7000			
	Production Costs	-70000	-70000	-70000	-93000
	Labor				
	Materials				
Utilities	Water				
	Electricity	-800	-1200	-800	-4000
	Gas		-2500	-2500	
	Steam				
	<i>Annual Operating Cash Flows</i>	(\$175,240)	(\$119,800)	(\$154,400)	(\$116,767)

Two cases were considered by XYZ for comparing alternative projects. Management wanted to see how the NPV would be affected if the discount rate was changed. Also, the financial analyst on the project team wanted to demonstrate the importance of depreciation calculations and how the depreciation tax shield could benefit this project. Table 4.4 is the cash flow summary for a 12% discount rate, showing NPV before and after considering depreciation. As shown, un-depreciated laser ablation looks un-attractive, with a NPV of -\$24,161. However when depreciation is considered, the NPV becomes \$25,007 and the project shows considerable benefit.

Also, one should note how difficult it is to judge a project using simple payback. If management arbitrarily screened projects based on a 4 year payback, both the unregulated solvent and laser ablation would be rejected. Every project, however, shows a positive NPV at the 12% discount rate. Furthermore, the aqueous cleaning system has the shortest payback, but the depreciated NPV for the alternative solvent system is higher.

Table 4.4: 12% Discount Rate

	<i>Annual Operating Cash Flows</i>	(\$175,240)	(\$119,800)	(\$154,400)	(\$116,767)
Cash Flow Summary		METH Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Income Tax	\$0	\$21,067	\$7,919	\$22,220
	= After Tax Cash Flow	\$0	\$34,373	\$12,921	\$36,253
	*pV factor = Present Value	\$0	\$194,214	\$73,005	\$204,839
	- Total Capital Costs	\$0	(\$179,000)	(\$40,000)	(\$229,000)
	= Net Present Value (NPV)	\$0	\$15,214	\$33,005	(\$24,161)
	Internal Rate of Return (IRR)	N/A	14.04%	29.95%	9.36%
	Simple Payback (years)	N/A	5.21	3.10	6.32
Considering Depreciation		Solvent Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Depreciation	\$0	(\$17,900)	(\$4,000)	(\$22,900)
	= Taxable Income	\$0	\$37,540	\$16,840	\$35,573
	Income Tax	\$0	\$14,265	\$6,399	\$13,518
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Income Tax	\$0	\$14,265	\$6,399	\$13,518
	= Dep. After Tax Cash Flow	\$0	\$41,175	\$14,441	\$44,955
	*pV = Depreciated Present Value	\$0	\$232,647	\$81,594	\$254,007
	Depreciated NPV	\$0	\$53,647	\$41,594	\$25,007
	Depreciated IRR	N/A	18.94%	34.20%	14.61%
	Depreciated Simple Payback	N/A	4.35	2.77	5.09

XYZ wanted to know how sensitive the projects were to a change in discount rate. Being conservative, management wanted to raise the rate a few points and see how the numbers looked.

In response, the team put together another table of cash flows at a 15% discount rate. Table 4.5 is a cash flow summary using the new numbers. At 15%, the laser ablation system is not feasible even after considering depreciation. Nor is the un-depreciated alternative solvent line. NPVs in these cases are less than zero; in some cases, much less than zero.

This result is not surprising. If one looks at the IRR for every project, those that are less than 15% (that is, less than the discount rate) generate NPVs less than zero. Remember what was stated earlier: IRR greater than the discount rate represents an economically beneficial project.

Table 4.5: 15% Discount Rate

<i>Cash Flow Summary</i>		METH Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Income Tax	\$0	\$21,067	\$7,919	\$22,220
	= After Tax Cash Flow	\$0	\$34,373	\$12,921	\$36,253
	*pV factor = Present Value	\$0	\$172,509	\$64,847	\$181,947
	- Total Capital Costs	\$0	(\$179,000)	(\$40,000)	(\$229,000)
	= Net Present Value (NPV)	\$0	(\$6,491)	\$24,847	(\$47,053)
	Internal Rate of Return (IRR)	N/A	14.04%	29.95%	9.36%
	Simple Payback (years)	N/A	5.21	3.10	6.32
<i>Considering Depreciation</i>		Solvent Cleaning	Unregulated Solvent	Aqueous Cleaning	Laser Ablation
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Depreciation	\$0	(\$17,900)	(\$4,000)	(\$22,900)
	= Taxable Income	\$0	\$37,540	\$16,840	\$35,573
	Income Tax	\$0	\$14,265	\$6,399	\$13,518
	Incremental Cash Flow	\$0	\$55,440	\$20,840	\$58,473
	- Income Tax	\$0	\$14,265	\$6,399	\$13,518
	= Dep. After Tax Cash Flow	\$0	\$41,175	\$14,441	\$44,955
	*pv = Depreciated Present Value	\$0	\$206,647	\$72,475	\$225,620
	Depreciated NPV	\$0	\$27,647	\$32,475	(\$3,380)
	Depreciated IRR	N/A	18.94%	34.20%	14.61%
	Depreciated Simple Payback	N/A	4.35	2.77	5.09

The problem shown above is not particularly complex. Hopefully it has demonstrated some of the tools needed to perform a simple economic analysis. The end of this section has a blank spreadsheet attached that may be used to perform these calculations by hand. In addition, an electronic file has been created that contains a Quattro Pro compatible spreadsheet to perform these calculations. For further information and a copy of this file, contact the Office of Technical Assistance. Another more

comprehensive software package is available. Written by the Tellus Institute, *P2/Finance*, ver 3.0, is a powerful spreadsheet for evaluating the economics of pollution prevention projects. The software is compatible with Microsoft Excel v.5.0 and Lotus 1-2-3 v.3.4a, and is available at no charge by calling OTA at (617) 626-1060.

For a more detailed economic analysis, including actual case studies from several companies in Massachusetts, refer to the Toxics Use Reduction Methods/Policy Report No. 6, *“The Cost of Changing”: Total Cost Assessment of Solvent Alternatives*.

Table 4.6: Sample Worksheet

Please complete
this chart:

Project Length (years)	Discount Rate	Tax Rate

		Current Process	Option 1	Option 2	Option 3	Option 4
	<i>Project Name</i>					
Capital Costs	Equipment Purchase	0				
	Installation	0				
	Old Process Disposal	0				
	Old Process Scrap value	0				
	Research & Design	0				
	Initial Permits	0				
	Building Changes	0				
	Utility Changes	0				
		0				
		0				
		0				
		0				
	Total Capital Costs	\$0				
Operating Cash Flows						
	Chemical Purchases					
Waste Management	Treatment Chemicals					
	Testing					
	Disposal					
	Safety Training					
	Safety Equipment					
	Insurance					
	Regulatory Fees					
	Regulatory Paperwork					
	Annual Permit Fees					
	Production Costs					
Maintenance Utilities	Labor					
	Materials					
	Water					
	Electricity					
	Gas					
	Steam					
	Annual Operating Cash Flows					

SECTION 5.0 USEFUL TOOLS FOR REGULATORY COMPLIANCE

5.1 INTRODUCTION

Numerous health, safety, and environmental regulations must be considered before implementing a cleaning system. Depending on the chemicals used in a cleaning system and the environmental releases involved (i.e., air, water or hazardous waste), more than one type of regulation may be applicable. This section provides an overview of the regulatory requirements potentially applicable to hazardous waste generation, air emissions, wastewater discharge and other regulatory concerns associated with cleaning systems. Table 5.1 identifies the regulations that may apply to the cleaning systems described in Section 2. This is only a summary of the regulations. To ensure compliance the full, updated text of the rules should be consulted.

5.2 HAZARDOUS WASTE MANAGEMENT

Waste from cleaning systems could be hazardous because of oil content, metal content, or the flammable properties of waste solvents. Waste from mechanical cleaning systems and emerging/highly specialized cleaning systems could be hazardous if it possesses one or more of the hazardous characteristics defined by the federal government.

The Massachusetts DEP regulates all non-households (businesses and institutions) which generate any amount of hazardous waste. 310 Code of Massachusetts Regulations (CMR) 30.000 contains the full Massachusetts hazardous waste regulations and the complete regulations are available at the State House bookstores. (The phone numbers for the State House bookstores are: (617) 727-2834, Boston and (413) 784-1378, Springfield.) EPA has given Massachusetts the authority to regulate hazardous waste. Massachusetts has chosen to adopt the federal definition of hazardous waste. Compliance with Massachusetts hazardous waste regulations ensures compliance with federal hazardous waste regulations.¹

For Massachusetts companies, two basic categories of waste are regulated as hazardous. One category, waste oil, is considered hazardous waste by the Commonwealth of Massachusetts. It is not hazardous by federal definition. The second category is waste that is hazardous by federal definition. The federal definition contains two criteria that determine hazard: 1) it may be specifically listed in the regulations (310 CMR 30.131-136), or 2) it may be defined by its hazardous characteristic (ignitability, corrosivity, reactivity, toxicity) (310 CMR 30.120). Specific definitions of the hazardous characteristics are shown in Figure 5.1. Either the chemical itself or waste containing the following chemicals may be ignitable and must be tested prior to disposal: semi-aqueous, petroleum distillates, aliphatic hydrocarbons, alcohols, NMP, ethyl lactate, acetone and VMS. Waste from other systems should be also tested to determine the applicability of hazardous waste regulations.

¹ Massachusetts Department of Environmental Protection, "A Summary of Requirements for Small Quantity Generators of Hazardous Waste," 11/1/95.

Table 5.1 Cleaning Systems Regulatory Matrix

				Wastewater Regulations		OSHA
	TURA	EPCRA 313	Hazardous Waste	POTW Discharge Permit	DEP Sewer Connection/ Extension Permit	
Aqueous			•	•	•	•
Semi-Aqueous	•	•	•	•	•	•
Alternative Solvents	<i>See Table 5.2 for a breakdown of the Alternative Solvents</i>					
Mechanical Cleaning			•	•	•	•
Emerging Technologies§	①	①	•	①	①	•

	VOC Air Regulations			VOC/HAP Air Regulations	HAP Air Regulations
	Massachusetts Record Keeping and Reporting (Emission Statement) 310 CMR 7.12	Massachusetts Plan Approval and Emission Limitations 310 CMR 7.02	Massachusetts VOC RACT 310 CMR 7.18	Federal Clean Air Act Title V Operating Permit	Federal Clean Air Act Title III NESHA (Solvent Cleaning MACT)
Aqueous					
Semi-Aqueous	•	•	•		
Alternative Solvents	<i>See Table 5.2 for a breakdown of the Alternative Solvents</i>				
Mechanical Cleaning	‡	‡			
Emerging Technologies§	①	①	①	①	

§ As described in the text.

‡ Mechanical cleaning systems may have particulate air emissions that could be regulated under this rule. Consult your state authority for more information.

• Indicates a high probability that this chemical will be subject to the provisions of this regulation.

① The very nature of emerging technologies prohibits the presentation of current regulatory information on this class of cleaning systems. Each system should be individually subjected to scrutiny to determine applicable regulations. The technologies described in the text have a *low* probability of being subject to the provisions of this regulation.

Table 5.2 Alternative Solvents Regulatory Matrix

				Wastewater Regulations		OSHA
	TURA	EPCRA 313	Hazardous Waste†	POTW Discharge Permit & DEP Sewer Connection Permit	Surface Water Discharge (NPDES) Permit	
Petroleum Distillates*	②	②	•			•
Aliphatic Hydrocarbons*			③			•
Alcohols*			•			•
NMP	•	•	③	④	④	•
DBE*			③			•
Glycol Ethers	⑤	⑤	③	④	④	•
Ethyl Lactate			③	④	④	•
Acetone*	•		•			•
VMS*			•			•
HFC*			③			•
HCFC*	⑤	⑤	③			•
HFE*			③			•
Chlorinated Solvents	•	•	•			•

* Assumes that this chemistry is not rinsed with water. If it is, the cleaning process may be subject to the wastewater regulations.

† Classification as “hazardous” may be based on flammability, toxicity, corrosivity, reactivity or if the chemical is specifically listed in the regulations. See the text for a more in depth discussion of hazardous waste.

• Indicates a high probability that this chemical will be subject to the provisions of this regulation.

② Although this class of chemicals may not be specifically listed in the regulations, it may contain a percentage of a reportable chemical.

③ Although the virgin chemical may be non-hazardous, the soils cleaned by this chemistry may cause the waste to be classified as hazardous.

④ This chemistry may be rinsed with water. If the discharge from rinsing is connected to a sewer, this regulation may apply.

⑤ This is a large class of chemicals. Some within this class may be reportable under this regulation, and some may not. Consult the regulation for more information.

	VOC Air Regulations			VOC/HAP Air Regulations	HAP Air Regulations
	Massachusetts Record Keeping and Reporting (Emission Statement) 310 CMR 7.12	Massachusetts Plan Approval and Emission Limitations 310 CMR 7.02	Massachusetts VOC RACT 310 CMR 7.18	Federal Clean Air Act Title V Operating Permit	Federal Clean Air Act Title III NESHAP (Solvent Cleaning MACT)
Petroleum Distillates	•	•	•	•	
Aliphatic Hydrocarbons	•	•	•	•	
Alcohols	•	•	•	•	
NMP	•	•	•	•	
DBE	•	•	•	•	
Glycol Ethers	•	•	•	•	
Ethyl Lactate	•	•	•	•	
Acetone	•				
VMS	•				
HFC	•	⑥	⑥	⑥ ⑦	
HCFC	•	⑥	⑥	⑥ ⑦	
HFE	•				
Chlorinated Solvents	•	•	•	•	•

• Indicates a high probability that this chemical will be subject to the provisions of this regulation.

⑥ Many chemicals in this class are exempt from VOC status. Exemptions are specifically listed in the regulations. See 40 CFR 51.100 and 310 CMR 7.00 for the current VOC status of your particular chemistry.

⑦ Although the Title V Operating Permit Program is a federal regulation, some states have assumed the responsibility for its implementation. If the state considers a chemical to be a VOC, the chemical can be subject to the Title V program, *even if it is federally exempt from VOC status*.

Generator status and applicable regulatory requirements are determined by the rate at which hazardous waste is generated. In the DEP publication entitled "A Summary of Requirements for Small Quantity Generators of Hazardous Waste" (See Appendix F), the table on page 5 summarizes status and regulatory requirements for waste oil and federal hazardous waste.

Definitions of Hazard Characteristics

Ignitability:	flash point below 140F
Corrosivity:	pH \leq 2 or \geq 12.5
Reactivity:	explosive, produces toxic gases when mixed with water or acid
Toxicity:	fails a toxicity characteristic leaching procedure test

5.3 AIR REGULATIONS

Of the cleaning processes described in Section 2, air regulations may apply to those employing VOCs and/or HAPs. Petroleum distillates, aliphatic hydrocarbons, NMP, DBE, ethyl lactate are VOCs. Certain alcohols, semi-aqueous solvents, HFEs, HCFCs and VMS may also be VOCs. If VOCs are emitted above a threshold level, then the appropriate air regulations apply. (See Appendix G for a list of VOC-exempt chemicals and HAPs.) Following is a description of five major regulations that are potentially applicable to air emissions from cleaning systems. Regulations 1,2 and 3 are specific to Massachusetts and will use the Massachusetts definition of VOC. Regulation 4 applies to specific solvents. Regulation 5 is federal but Massachusetts has the authority to apply it so the Massachusetts definition is used. The air regulations that apply to chlorinated solvents and hazardous air pollutants are also included because this information may be useful in projecting regulatory compliance costs for existing systems (Title III MACT Standard). For more information, consult the Massachusetts DEP's "VOC Regulations - Applicability Guidance," included in Appendix H.

1. Record Keeping and Reporting - Emission Statement (310 CMR 7.12)

Sources of air emissions with potential emissions exceeding 10 tons per year of organic material or particulate matter must file an emission statement with DEP.¹ The *potential emission* of organic material is calculated based on operating cleaning equipment using VOCs at maximum capacity, 24 hours per day, 365 days per year. The data and information filed provides an after-the-fact record of actual emissions.

¹ Sulfur oxides and nitrogen oxides are also regulated as air pollutants. Because these are not typically an issue with cleaning systems, they are not addressed in this Guidebook.

2. Plan Approval and Emission Limitations (310 CMR 7.02)

Pre-construction approval permits are required for the construction or modification of any pollution source (except incinerators and boilers) with an increase of more than one ton per year of potential emissions of regulated air contaminants (including particulate matter, volatile organic compounds, and halogenated organic compounds (HOCs))¹. New or modified sources are exempt from approval if they have less than one ton per year of potential emissions. However, records must be kept at the facility to document the fact that potential emissions of all regulated pollutants are less than one ton per year. Limited plan approvals (LPAs) are required for new and modified sources with potential air emissions of 1-5 tons per year and comprehensive plan applications (CPAs) are required for new and modified sources with potential emissions greater than 5 tons per year. LPAs can generally be done in-house while the process for obtaining a CPA is more complex. CPAs must be signed by a registered professional engineer.

Restricted Emission Status (310 CMR 7.02 (12))

Since permitting requirements for larger sources are more complex than for smaller sources, companies may find it beneficial to file for a permit restriction that limits their potential emissions. For example, this strategy might be used to change a facility's status so that a LPA is required instead of a CPA. A permit restriction amounts to a binding agreement with state regulators to impose certain physical or operational limits on potential emissions, typically by restricting hours of operation or raw material consumption, or by using pollution control equipment. These limitations cannot be exceeded without prior written approval, and such approval would require a new permit application or permit modification, depending on the amount of increase.

3. Reasonably Available Control Technology (310 CMR 7.18(8))

Existing sources of air pollutants specifically cited in the regulations are required to obtain permits for operation. Facilities having operations using VOCs could be regulated as existing sources. The regulations for sources of VOC emissions are often referred to as VOC RACT (reasonably available control technology). The RACT category for solvent metal degreasing is included in Appendix I for reference.

4. Clean Air Act Amendments - Title III MACT Standard - Solvent Cleaning

In December, 1994, the U.S. Environmental Protection Agency issued national regulations to control toxic air pollutant emissions from solvent cleaning machines (immersion cold cleaning and vapor degreasing) that use any of the following halogenated solvents: methylene chloride, perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, and chloroform.² The standards give solvent cleaning sources operating batch or in-line degreasers three options for compliance: (1) install one of several combinations of emission-control equipment and implement automated parts handling and specified work practices (including an operator test), (2)

¹ Sulfur dioxide, nitrogen dioxide and carbon monoxide are also regulated here. Because these are not typically an issue with cleaning systems, they are not addressed in this Guidebook.

² US EPA Office of Air Quality Planning and Standards (MD-13), EPA-453/F-94-083, March 1995- New Regulation Controlling Air Emissions from Solvent Cleaning Machines (Degreasers).

meet an idling-mode emission limit, in conjunction with parts-handling and work practice requirements (with an operator test), or (3) meet a total emissions limit¹. All owners and operators of any size solvent cleaning machine at any size facility that uses one of the six solvents or any combination of these solvents in a total concentration greater than 5% by weight is affected by this regulation.

5. Clean Air Act Amendments -Title V Operating Permit

The purpose of an operating permit is to compile all approvals, permits and requirements relating to air pollution for a facility into one document and permit. All facilities that are major sources of air pollution, or any new proposed major source of air pollution must apply. In general, major sources include facilities with the potential to emit one or more of the following²:

- 50 tons per year of VOC
- 10 tons per year of a single hazardous air pollutant (HAP)
- 25 tons per year of all HAPs combined
- 100 tons per year of total suspended particulates, sulfur dioxide, or carbon monoxide

Facilities are divided into three groups, A, B, and C, according to the facility's two digit SIC code. Groups A, B and C correspond to applications BWP AQ 15, 16, and 17 respectively. While the application form is the same for all groups, the time lines for review and required date of submittal are not the same. These permits are in effect for five years unless otherwise stated in the approval or unless modifications to the facility require that a new or modified permit be issued. These regulations include, but are not limited to:

- Air Pollution Control Regulations, 310 CMR 6.00-8.00
- Timely Action and Fee Provisions, 310 CMR 4.00³

(Note: These may be purchased at the State House Bookstores. The phone numbers for the bookstores are: 617-727-2834, Boston and (413) 784-1378, Springfield.)

Any cleaning system that uses one or more VOC or HAP may have potential emissions that exceed the thresholds. In this case, the facility would be a major source of air pollution and thereby subject to operating permit regulations and requirements.

¹ "The Looming Deadlines for Degreasing NESHAPs" Industrial Paint and Powder, March 1995.

² Major sources are also identified by emissions of 50 tons per year of nitrogen oxides (NOx) or 100 tons per year of sulfur dioxide or carbon monoxide. Because these are not typically an issue with cleaning systems, they are not addressed in this Guidebook

³ Massachusetts Department of Environmental Protection, Bureau of Waste Prevention, Air Quality Control, Operating Permits- BWP AQ 15, 16, 17 Guidance Rev. January, 1995.

50% or 25% Facility Emission Cap (310 CMR 7.02 (15))

This regulation is a streamlined process for a facility with high potential emissions but low actual emissions to certify that the actual emissions will never exceed 50% or 25% of all the major thresholds and avoid certain "major source" requirements of the Clean Air Act. Electing this notification process would be equivalent to applying for Restricted Emission Status (RES) under 310 CMR 7.02 (12) without the permitting process. Operating under one of these emission caps, the facility's actual emissions in the prior year must be equal to or less than the emission cap. For facilities electing the 50% emission cap, the facility's actual emissions in every 12 month period (rolling 12 months) must be equal to or less than the emission cap. For example, if a facility with VOC emissions elects the 50% emission cap, the facility's actual VOC emissions in every 12 month period (rolling 12 month) must be equal to or less than 25 tons per year of VOC. For those electing the 25% emission cap for VOCs, the rolling 12 month emissions must be equal to or less than 15 tons per year of VOC. The emission cap would be different for HAPs and suspended particulates because of different major source thresholds for these pollutants. The permit and compliance fees for the 50% or 25% facility emission cap notification are much less than those for the permit restriction of 310 CMR 7.02 (12).

5.4 TOXICS USE REDUCTION

Of the cleaning chemicals described in Section 2, the following appear on the Toxics Use Reduction List of Toxic and Hazardous Materials: petroleum distillates (while not specifically listed, components may be listed), NMP, acetone, chlorinated solvents. In addition certain chemicals in the semi-aqueous, glycol ether, and HCFC categories are also included. The Toxics Use Reduction Act (TURA, 310 CMR 50.00) applies to facilities within the following SIC Codes:

- | | |
|------------------------------|------------------|
| ➤ 1000-1400 | Mining |
| ➤ 2000-3900 | Manufacturing |
| ➤ 4000 and 4400-4900 | Transportation |
| ➤ 5000 and 5100 | Wholesale |
| ➤ 7200, 7300, 7500, and 7600 | Certain Services |

Two additional factors determine the applicability of TURA to a facility. The equivalent of ten or more full-time workers must be employed and the facility must annually manufacture or process at least 25,000 lb. or otherwise use at least 10,000 lb. of any chemical on the TURA list. If one of the usage thresholds is exceeded, the TURA threshold becomes 10,000 lb. for any listed chemical that is manufactured, processed, or otherwise used at the facility. If a facility meets all three criteria (SIC code, full time employee equivalents, and chemical usage), it is considered a "large quantity toxics user" (LQTU) and has obligations under TURA. As an LQTU, the facility is required to:

1. Submit an annual toxics use reduction report to the Massachusetts DEP.
2. Every other year develop a toxics use reduction plan or plan update and submit a summary to DEP.
3. Pay an annual fee related to the number of chemicals subject to TURA reporting and the number of employees.

See 310 CMR 50.00 (Reporting, Confidentiality, and Planning), 301 CMR 40.00 (TURA Fees), and 301 CMR 41.00 (TURA Chemicals) for additional information. This is also available online at www.magnet.state.ma.us/dep. Contact the Office of Technical Assistance at (617) 626-1060 or DEP's Toxics Use Reduction Program at (617) 292-5982 for more information or for a copy of the regulations.

5.5 SECTION 313 OF THE EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT (EPCRA)

Of the cleaning chemicals described in Section 2, the following appear on the EPCRA list of chemicals: petroleum distillates (while not specifically listed, components may be listed), NMP and chlorinated solvents. In addition certain chemicals in the semi-aqueous, glycol ethers, and HCFC categories are also included. Section 313 of EPCRA requires that reports be filed by owners and operators of facilities that meet all of the following criteria:

1. The facility has 10 or more full-time employees
2. The facility is included in Standard Industrial Classification (SIC) Codes 20 through 39
3. The facility manufactures (defined to include importing), processes, or otherwise uses any EPCRA listed toxic chemical in quantities greater than the regulatory threshold (25,000 lb. for manufacturing or processing and 10,000 lb. for otherwise used) in the course of a calendar year.

Reporting is required to provide the public with information on the releases of listed toxic chemicals in their communities and to provide EPA with release information to assist the Agency in determining the need for future regulations. Facilities must report the quantities of both routine and accidental releases of listed toxic chemicals, as well as the maximum amount of the listed toxic chemical on-site during the calendar year and the amount contained in wastes transferred off-site.¹

5.6 WASTEWATER DISCHARGE

Wastewater discharges from aqueous and semi-aqueous cleaning systems and possibly from mechanical cleaning systems that use water could require a permit and approval from both DEP and the local authority.

¹US EPA, Office of Pollution Prevention and Toxics, Toxic Chemical Release Inventory, Reporting Form R and Instructions- Revised 1995 Version, March 1996.

DEP Industrial Wastewater Management- Sewer Connection Permits

Non-sanitary industrial wastewater discharge to a septic system is not permitted in Massachusetts. Any facility with industrial wastewater discharge to a sewer system should contact the local wastewater treatment plant to discuss the need for and obtain a discharge permit, if required. Such a permit may be necessary because of the presence of organic material, acidic or alkaline contaminants, suspended solids, metals, or material that could cause a biological or chemical oxygen demand. There may be additional parameters to consider and discuss with the treatment plant in relation to industrial wastewater discharge from cleaning systems. In addition to the permit from the local governing authorities, it may be necessary to obtain a DEP sewer permit. If one or more of the following conditions is met, a facility is required to obtain a DEP sewer connection or extension permit:

1. Wastewater discharge is 15,000 gal. per day or greater.
2. There is an extension of the sewer connection.
3. A pumping station is used.

The local wastewater treatment plant must sign off on any application for a DEP sewer connection or extension permit.

Surface Water Discharge (National Pollutant Discharge Elimination System) Permits

Any facility with an industrial wastewater discharge must apply for one of these permits if it wishes to discharge to surface waters in Massachusetts. There are no thresholds based on the amount of discharge. Applicants should apply to the EPA at the same time they apply to DEP. DEP will not begin its technical review of the application until after DEP is provided with a draft permit from EPA for the proposed discharge. Questions about surface water discharge permits can be phoned to DEP's Office of Watershed Management at (508) 792-7470.¹

5.7 OSHA CONSULTATION PROGRAM

All cleaning systems have some potential for hazard to the worker who operates them; companies and workers could benefit from an OSHA consultation. By using a free consultation service largely funded by OSHA, Massachusetts employers can find out about potential hazards at their worksites, improve their safety management systems, and may qualify for a one-year exemption from routine OSHA inspections. Most consultations take place on-site, using professional staff employed by the Massachusetts Department of Labor and Workforce Development. This safety and health consultation program is completely separate from the OSHA inspection program and no citations are issued or penalties proposed. The service is confidential and any information provided about unsafe or unhealthful working conditions at the workplace will not be reported to OSHA inspection staff. However, a commitment to correct serious job safety and health hazards is expected prior to the actual visit. This commitment should be discussed with the Department of Labor and Workforce Development prior to the visit.

During the walk-through, the consultant studies the entire plant or specific operations designated and discusses applicable OSHA standards. During the closing conference, problems, possible solutions, and abatement periods to eliminate or control any serious hazards are discussed.

If the consultant finds an "imminent danger" situation, immediate action must be taken to protect employees. In "serious violation" situations (under OSHA criteria), the employer and consultant are required to develop and agree to a reasonable plan and schedule to eliminate or control the hazard. If identified serious hazards (or an imminent danger) are not eliminated or controlled (according to the plan and within limits agreed upon), the situation must be referred from consultation to an OSHA enforcement office for appropriate action.²

Contact the Commonwealth of Massachusetts, Department of Labor and Workforce Development, Division of Occupational Safety, On-Site Consultation Service at (617) 727-3463 for a free health consultation.

¹ Massachusetts Department of Environmental Protection, Master Permit Guide, Industrial Wastewater Management, Surface Water Discharge (NPDES) Permits, March 1995, Pg. IW 9.

² Commonwealth of Massachusetts, Department of Labor and Workforce Development, Division of Occupational Safety, "The OSHA Consultation Service."

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